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A GIS Spatial Analysis of the Potential Conflict between Submerged Aquatic Vegetation Management and the Development of Shellfish Aquaculture in the Lower Chesapeake Bay

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A GIS SPATIAL ANALYSIS OF THE POTENTIAL CONFLICT BETWEEN SUBMERGED AQUATIC VEGETATION MANAGEMENT AND THE DEVELOPMENT OF SHELLFISH AQUACULTURE IN THE LOWER CHESAPEAKE BAY

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF FIGURES (cont.)

LIST OF FIGURES (Continued)

LIST OF TABLES

ABSTRACT

Multi-use conflicts are inevitable in highly utilized coastal regions. Coordinated policies, integrating traditional activities, generally exist in a region's coastal management plan. These plans seek to minimize these conflicts; however, when traditional activities expand their usual boundaries, or new activities are introduced into these populated areas, the potential for use conflicts increases. Clear proactive environmental planning is necessary to craft policy and regulations to minimize this potential increase in conflict.

Shallow water shellfish aquaculture, utilizing both on-bottom and off-bottom techniques, is currently expanding in Chesapeake Bay. This expansion could potentially cause various types of use conflicts to develop. Preliminary studies indicate that conflicts between shallow water aquaculture and the preservation/restoration of submerged aquatic vegetation (SAV) in the Bay, are likely to evolve, unless coordinated management is executed.

This research is the first known attempt at developing a large scale spatial analysis using Geographic Information System (GIS) to delineate suitable sites for both activities in the lower bay. Ultimately the results of this research are to be used as a guideline for strategic management planning and policy formation. Management directives are recommended based on the results of the analysis, i.e. delineating areas as unlimited, limited and prohibited for aquaculture development based on the likelihood of SAV habitation. Due to limitations of the GIS analysis, a general comparison of relative site suitability and not a refined analysis, resulted. With improved data sets and a more accurate biophysical scoring system, future analyses, based on this protocol could produce results with much finer resolution. Even with it's present shortcomings, this first attempt at developing a spatial analysis to proactively minimize use conflict between shellfish aquaculture and SAV restoration, can prove to be an important management tool. It provides managers with valuable insights, to be used in conjunction with today's site-by-site permitting, when developing aquaculture policy.

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INTRODUCTION

Multi-use conflicts occur when two or more activities compete for the same limited space or resource. In highly populated coastal regions, such as the Chesapeake Bay, these conflicts are inevitable but can be minimized if strategic planning and coordinated policy are executed at an early stage. Policies designed to regulate and coordinate traditional uses, such as commercial fishing, navigation, and recreation have long existed in the Virginia State Code. The potential for conflict between these uses has thereby been decreased through clear planning and policy. Problems arise however, when a traditional use expands its usual boundaries and/or a new use, not formerly addressed in the codes, is introduced into the already highly populated area. Shellfish aquaculture in the lower Chesapeake Bay is a good case in point.

Shallow water shellfish aquaculture is becoming quite popular in the lower Bay waters. Traditional on-bottom techniques are expanding and new off-bottom techniques are being deployed. With this increase in operations, comes the increased potential for use conflicts to occur. DeVoe and Pomeroy (1992) categorized aquaculture use conflicts into five basic types: land\water property rights, traditional uses, compatibility with natural resources, species conflicts, and complexity of the economic, environmental and political response.

All five types of user conflicts listed above can potentially arise in the Chesapeake Bay with the expansion of shallow water shellfish aquaculture (Neikirk 1990). Comprehensive analyses addressing these potential conflicts are necessary in order to successfully incorporate this growing activity into the regional coastal zone. This research focuses on the potential use conflict between the development of shallow water shellfish aquaculture (all techniques are included in this heading, i.e., on-bottom and off-bottom: suspended and floating) and the management policies promoting the preservation\restoration of submerged aquatic vegetation (SAV). This research, therefore, falls under DeVoe and Pomeroy's third type of aquaculture use conflict, compatibility with a natural resource.

As early as the late 1800's, Virginians were encouraged to cultivate oysters. Private leasing became an important factor in the oyster industry, and up until the 1960's, leased acreage steadily increased. The most common technique for oyster cultivation was on-bottom planting. On-bottom clam cultivation started decades later in Virginia but over the past two decades has become quite successful.

Although on-bottom clam and oyster culture have existed in the Commonwealth for some time, the majority of Virginia's commercial supplies have historically come from the harvest of wild stocks. Over the last century, however, these natural harvests have declined (Haven et al. 1978; Osterling 1993). Increased bay pollution, the invasion of new pathogens, and the overharvesting of species, have all contributed to the declines in the fisheries. The Commonwealth is beginning to explore alternative methods to augment its commercial catch as well as restore the Bay's natural filtering system. In the late 1980's, the Commonwealth initiated an aquaculture development task force to promote the expansion of aquaculture in Virginia. In addition to the traditional on-bottom oyster and clam culture, a variety of new culture methods (off-bottom suspended and floating trays and racks) and species (bay scallops, mussels, surf clams and softshell clams) are now gaining attention in the region. Presently, in Chesapeake Bay there are approximately 32 clam aquaculture sites, 36 oyster aquaculture sites, and a few bay scallop aquaculture sites spread throughout the lower Bay (Oesterling 1993). Little policy exists to coordinate these expanding operations with other uses.

As the Commonwealth is addressing the potential expansion of aquaculture, it is also recognizing the urgent need to preserve and restore SAV in the Chesapeake Bay. SAV performs many important functions in the Bay ecosystem (Orth and Moore 1981). Comprised of a diverse group of rooted flowering plants, SAV has adapted to living completely submersed. Since growth is limited by light availability (Backman and Barilotti 1976), SAV is found in the shallow subtidal zone. In the early 1970's, SAV experienced a drastic decline in acreage (Orth and Moore 1983). Anthropogenic factors (i.e., excess nutrient and sediment inputs into the Bay), were major contributors to the decline (Kemp et. al. 1983). Policy and regulations have been created to encourage the preservation and restoration of SAV (Chesapeake Executive Council 1989, 1990). The Chesapeake Bay Program recently set a baywide restoration goal of 247,658 hectares, approximately ten times the area presently covered by SAV (Batiuk, et. al. 1992).

Preliminary research comparing the habitat requirements for both SAV growth and successful oyster aquaculture (conducted by the Coastal Inventory Program at VIMS), suggests that the potential for desired sites for each activity to overlap is probable if the two continue to develop and their regulations and management are left uncoordinated.

To date the positioning and permitting of shallow water aquaculture operations has been based on site-by-site inspection. The placement of an aquaculture operation is usually based on the following factors; areas where the culturist already owns property and areas where bio-physical conditions (such as salinity, current speed, and chlorophyll concentrations) are suitable for the successful growth of the cultured species. This method alone could lead to biassed decisions given that it lacks the large scale vision necessary to craft policy geared toward proactively coordinating aquaculture development and SAV preservation/restoration. Although new policy on SAV promotes the general avoidance of SAV destruction when constructing aquaculture operations, no comprehensive management plan, based on present and potential SAV conditions exists to strategically place shellfish culture operations in certain areas so as to minimize use-conflict.

This research is the first known attempt at creating a spatial analysis protocol to act as a basis to proactively manage the placement of aquaculture operations and thereby decrease the potential use conflict between these sites and the preservation/restoration of SAV in the lower Chesapeake Bay.

<u>The objectives of this work are to</u>:

1. Develop a spatial analysis protocol using Geographical Information System (GIS) and existing data sets to identify and delineate areas suitable for shellfish aquaculture and SAV growth.

2. Analyze the distribution trends of the suitable areas and identify and delineate overlapping regions.

3. Discuss possible management directions based on the resulting spatial analysis that could minimize potential conflict.

BACKGROUND/LITERATURE

I. SAV

A. Biology

Submerged aquatic vegetation (SAV), is a diverse group of vascular plants which have evolved to an existence completely submerged (Hurley 1990). There are over 500 species of SAV worldwide with approximately 20 found in the Chesapeake Bay (Hurley 1990, Orth and Moore 1981).

SAV species are distributed according to different salinity tolerances. In the Virginia portion of Chesapeake Bay, where salinities are mesohaline (>5-18ppt) to polyhaline (>18ppt), two species dominate: Zostera marina (eelgrass) and Ruppia maritima (widgeon grass). Species such as Vallisneria americana (wild celery), Potamogeton pectinatus (sago pondweed) and Potamogeton perfoliatus (redhead grass) are found in the middle and upper sections of the Lower Bay's tributaries where salinities range from mesohaline to fresh (<0.5 -5ppt) (Funderburk, et. al. 1991).

SAV performs many important functions in nearshore waters (Orth and Moore 1981; Funderburk, et. al. 1991). SAV is a major source of food for waterfowl (Martin and Uhler 1951). It serves as a habitat and nursery ground for a variety of fish and invertebrates as well as an attachment site for algae and eggs (Orth and Heck 1980). SAV beds play a major role in absorbing excess nutrients which enter the Bay and its tributaries through anthropogenic and natural pathways (Boynton and Heck 1982). Extensive root systems help control shoreline erosion as well as decrease suspended sediments in the water column (L. Hurley 1990).

SAV populations are extremely sensitive to their surrounding environmental conditions and therefore may be highly dynamic. In Chesapeake Bay, SAV have experienced fluctuations in species distribution and abundance on various spatial scales resulting from both natural and anthropogenic causes (Orth and Moore 1984).

In the early 1930's, Zostera marina, commonly known as eelgrass, underwent a dramatic decline. During the "wasting disease" as the loss was termed, over 90% of the species throughout its entire Atlantic range was destroyed (Tutin 1942). Subsequent recovery was noted in many locations in the Chesapeake Bay (Orth and Moore 1984).

A large baywide decline in the late 1960's and 1970's affected not only Zostera but all indigenous SAV species (Orth and Moore 1983). The decline was attributed to increasing nutrient enrichment and sedimentation as a result of change in land use and population in the surrounding watershed (Kemp, et. al. 1983). The decline was more severe than the 1930's because all species were affected and recovery has been minimal for some species. (Orth and Moore 1984). Currently, approximately 25,000 ha of SAV exist in the Chesapeake Bay (Orth et al. 1991), an estimated 10% of its historical distribution (Stevenson and Confer 1978).

Aerial photography is commonly used to map SAV distribution.

Because SAV is vital to the Bay's health and can potentially act as a general health barometer of the ecosystem's condition (Orth and Moore 1988), attention has been focused on decreasing the factors leading to the decline of SAV systems. In the 1987 Chesapeake Bay Agreement the... 'need to determine the essential elements of habitat quality and environmental quality necessary to support living resources and to see that these conditions are attained and maintained...,' was set as a major priority (Batiuk, et. al. 1992).

Over the past decade considerable research has focussed on the relationship between SAV and water quality, to clarify the habitat requirements necessary for successful SAV growth and restoration (Dennison et al. 1992; Batiuk et al. 1992) In the Chesapeake Bay five primary habitat requirements where found to affect the survival and restoration of SAV: light attenuation, total suspended solids, chlorophyll a, dissolved inorganic nitrogen and dissolved inorganic phosphorus. Each requirement has been assigned a minimal target value for restoration. Some of these values vary according to different salinity ranges (See Table 1.).

In addition to the establishment of habitat requirement values, Batiuk et. al. (1992) also establish restoration targets for SAV as a mechanism to determine the effectiveness of efforts to improve water quality. Three tiers representing increasing acreages were delineated.

TIER I : Restoration of SAV to areas currently or previously inhabited by SAV as mapped through regional and bay wide aerial surveys from 1971 through 1990.

TIER II: Restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat down to the one meter depth contour. A number of areas are excluded from this tier due to high wave energy.

TIER III: Restoration of SAV to all shallow water areas delineated as existing or potential SAV habitat down to the two meter depth contour (247,659 hectares potentially).

A 1993 directive by the Chesapeake Executive Council set Tier I as an interim recovery goal. If current rates of recovery continue, the Chesapeake Bay Program expects to reach the Tier I goal by the year 2005 (Maryland Sea Grant College 1994).

B. Summary of Pertinent Federal and State Policy and Regulations

Along with the increased knowledge of SAV's important ecological role and its habitat requirements, has come the increased awareness of the necessity to establish sound policy to protect and restore SAV in the Chesapeake Bay. Numerous state and federal policies exist to achieve this goal.

The Chesapeake Executive Council developed the Submerged Aquatic Vegetation Policy (Chesapeake Executive Council 1989) and Implementation Plan for SAV (Chesapeake Executive Council 1990) with the overall goal of achieving a net gain in SAV distribution and abundance. The policy's three major goals are :

1. Protecting existing SAV;
2. Setting and achieving regional water and habitat quality goals and thereby restoring SAV through natural revegetation; and
3. Setting regional SAV restoration goals, considering historical distribution records and estimates of potential habitat.

Under this policy, the siting of rack structures over existing and/or potential SAV beds is strongly discouraged. "Only in rare circumstances will losses of submerged aquatic vegetation be considered justifiable " (Chesapeake Executive Council 1990). "In addition to protection of SAV, shallow water habitat that once supported SAV, that is adjacent to current SAV bed locations, or that has the potential to become revegetated by SAV should also be given a high level of consideration by all federal, state, and local regulatory programs. To achieve a net gain in SAV, potential SAV habitat must also be protected " (Chesapeake Executive Council 1990).

The Policy goes on to say that the signatories to the

SAV Policy should review their current programs to ensure that they provide adequate protection of this natural resource. Modifications of existing programs or development of new programs may be necessary to implement the intent of the SAV policy. Additionally it is suggested that prior to the issuance of any federal, state, or local permit, all reviewing agencies should seek to avoid any damage to SAV. In cases where damage is unavoidable, such rare circumstances must be identified and agreed to by all reviewing agencies. Measures to minimize unavoidable impacts must also be developed and agreed upon by the agencies involved.

In addition to the specific SAV policy described above, a specific section in Title 28.2 (previously found under Title 61.2) of the Virginia Code provides SAV with some protection. The Subaqueous Law as this section is commonly called, requires the issuance of a permit to "...build, dump, or otherwise trespass upon..." state bottoms. When issuing a subaqueous permit, the Virginia Marine Resource Commission must consider its impact on other permissible uses of state waters and bottomlands, marine and fisheries resources, wetlands, adjacent properties and water quality. The accompanying Subaqueous Guidelines discourage the use of SAV beds for dredged material disposal as well as the destruction of SAV when locating submerged structures. In theory, this law protects SAV, however its effectiveness can be debated. The law falls short of protecting SAV from the many permitted uses of Title 28.2, which do not receive any environmental review from the state. Some of the permitted uses of Title 28.2 are the erection of a dam, certain fisheries activities, congressionally approved navigation and flood control projects, state port facilities and private noncommercial piers. A recent point of debate centers around the permitted use named above as "certain fisheries activities". A section of Title 28.2 (previously found under Title 28.1) outlines the process of leasing state owned bottoms for the purpose of planting or propagating shellfish. In the past, once an area has been leased for this purpose, no additional permission was necessary to cultivate the shellfish. This allowance has often meant that SAV beds were destroyed by either the placement of shells as cultch or by harvesting techniques. An old oyster culture handbook published by the Virginia Institute of Marine Science had an entire section entitled "Controlling Eelgrass", it explained that the placement of tar paper and sand would help oystermen "reclaim ground that was infested with eelgrass" (Bailey and Biggs 1958).

In addition to the state code, federal laws attempt to protect SAV in numerous ways. The Rivers and Habors Act of 1899 (33 U.S.C. 403, 33 CFR, Subsection 322.3a), requires a permit be issued under Section 10 by the Department of the Army for structures and/or work in or affecting navigable waters of the United States. In the summer of 1992 a public notice was issued regarding the proposed modification of Regional Permit #19. The modification was developed to reduce the regulatory duplication and delay for minor activities having minimal environmental effects, particularly small scale aquaculture operations. A list of strict qualifications however are cited, and the first one states, "No activity shall occur within beds of eelgrass, widgeon grass, or saltmarsh, nor shall such vegetation be damaged or removed." The Federal Water Pollution Control Act, as amended (33 U.S.C. 466 et seq.) in Section 401 gives the states the opportunity to require a permit for any discharge into navigable waters. Under Section 404, a permit is required by the Department of the Army for the discharge of dredged or fill material into the waters of the United States. These laws allow states like Virginia to monitor the activities affecting the water quality of existing and potential SAV habitats.

II. AQUACULTURE

For thousands of years aquaculture has provided people with a variety of seafood products (Menzel 1991, Neikirk 1990). Today many countries rely heavily on aquaculture to meet the consumer demands of their growing populations. In 1985, for example, Japan was utilizing an area of the ocean floor for aquaculture which equalled the same amount of land it was utilizing for agricultural purposes (Waters 1991).

In comparison to some Asian and European countries, the United States has not as yet developed aquaculture to its full potential. United States congressional findings (Ch. 48 Aquaculture 16 SS 2801) state that this country imports over half of all its fish and shellfish. Additionally, they found that although aquaculture currently contributes approximately 10% of world seafood production, less than 3% of current U.S. seafood production results from aquaculture. These statistics, coupled with the knowledge that many of the U.S. commercially harvested species are at or below their maximum sustainable yields, have lead Congress to develop national policy to promote and encourage the development of U.S. aquaculture.

The National Aquaculture Act passed in 1980, stated that it is national policy.... "to encourage the development of aquaculture in the United States...." (P.L. 96-362). In 1985, the National Aquaculture Improvement Act was created and replaced the earlier act. The 1985 act named the

Department of Agriculture the lead agency for the development of aquaculture in the United States. The act additionally established a National Aquaculture Information Center to help disseminate the latest culturing facts and technology throughout the country (Neikirk 1990).

Although the national policy is to encourage and promote the development of aquaculture, the degree of aquaculture development at the state level varies throughout the United States (Theberge and Neikirk 1987). Some coastal states, such as Maine and Florida, have developed beneficial aquaculture techniques and legislation. (DeVoe and Mount 1989; Edgerton 1992). On the west coast, intensive oyster and salmon aquaculture programs have been established in California, Washington and Oregon (Neikirk 1990). In contrast to these states however, some states have only recently begun to seriously consider aquaculture as a feasible alternative to traditional harvesting practices.

Until recently, the Commonwealth of Virginia has relied mainly on traditional harvesting methods to meet seafood consumer demands. Although on-bottom oyster and clam culture have historically been used to augment the Commonwealth's wild harvests, these ventures have been comparatively small. Presently, however, with the decline of natural harvests in Virginia waters, coupled with the increase in U.S. seafood demand, the economic incentive necessary to spark aquaculture development in Virginia appears to be growing.

In the late 1980's, the Commonwealth initiated an aquaculture development task force, with the objective of promoting all aspects of aquaculture. Among the marine species presently being focused on by the task force are oysters (Crassostrea virginica) and hard clams (Mercenaria mercenaria). Future attention is expected to concentrate on the bay scallop (Argopectin irradians), the ribbed mussel (Guekensia demissa), the surf clam (Spisula solidissima) and the softshell clam (Mya arenaria) (Osterling 1993).

Over the last century Virginia's average landings of the American oyster, Crassostrea virginica, have rapidly declined from approximately 6.5 million bushels at the turn of the century (Horton and Eichbaum 1991) to 46,507 bushels landed in the 1992-93 season (Virginia Marine Resource Commission 1993). An estimated one percent of a once thriving oyster population now exists in the Bay (Horton and Eichbaum 1991).

The combined effect of years of overharvesting, increased pollution and the spread of two oyster pathogens, has caused the collapse of the traditional fishery and the near eradication of the American oyster in the Chesapeake Bay (Menzel 1991). The loss of this once abundant species is both a loss to the economy of the area as well as the ecology of the Bay waters.

The oyster was once the leading commercial fishery in the bay supplying a high consumer demand. As an integral part of the Bay's ecosystem, oysters provided the bay with a natural filtering system, cleansing the water with high efficiency. The decline in oysters has apparently contributed to system level changes, including eutrophication, increased hypoxia and anoxia, and trophic alterations (Newell 1988, Ulanowicz and Tuttle 1992). Along with the American oyster, Virginia marine aquaculture is focusing on the hard clam, Mercenaria mercenaria. A decline in natural stocks coupled with stable demand has resulted in the expansion of hard clam mariculture (Mojica and Nelson 1993). Cultured clams now make up 43% (Cato 1991) of the U.S. clam harvest. Over the past few decades, the commercial culture of clams in Virginia has become quite successful.

The first commercial clam hatchery in the U.S. was established on Virginia's Eastern Shore in 1956. Hindered by biological, social, legal and economic factors, the development of clam culture in Virginia has been slow. Despite the obstacles, the last two decades have proven the great potential in Virginia clam culture. Virginia now has approximately 32 clam operations in existence. One of these sites is the largest operation in production on the East coast (Osterling 1993). With this success, further expansion is likely.

The bay scallop, once an abundant harvest in Virginia, disappeared from the seaside lagoons of the Eastern Shore in the 1930's. Historically known for its sweet adductor meat, the whole bay scallop is now being successfully marketed in gourmet restaurants on the eastern coast. The cultured product therefore appears to have a high potential demand (Oesterling pers. comm. 1993).

Many factors make Virginia waters prime locations for shellfish aquaculture. The Eastern Shore is an ideal location for culture operations because of its relatively pristine waters, extensive shallow water inlets and its central location to major cities such as Richmond, VA., Washington, D.C. and Baltimore, MD. (Neikirk 1990). The bayside of the Eastern Shore supports both clam and oyster operations and the seaside supports bay scallop operations.

Experiments demonstrating the technical feasibility of culturing oysters, clams and bay scallops in Virginia waters have been conducted over the past several decades by scientists in Virginia as well as many other states (Waters 1991; Castagna and Kraeuter 1977 and 1981; Castagna 1983; Brotman 1992). Certain aquaculture methods, namely off-bottom and suspended techniques, offer a growth advantage over traditional shellfish grow-out methods. All of the bivalves discussed above are suspension-feeders. Animals living on or near the bottom may spend considerable energy separating unwanted sand and silt from nutritious food particles. Though hard clams grow more rapidly on the bottom; oysters and scallops clearly achieve more rapid growth rates when suspended above the bottom. In the Chesapeake Bay, the most important advantage of a rapid growth rate for an oyster culturist is an increased chance of the product reaching market size before local pathogens destroy it. The two most destructive oyster diseases, Haplosporidum nelsoni (MSX) and Perkinsus marinus (Dermo), usually strike the oysters in their second summer, one year before they are typically harvested. The stratagem is therefore to grow the oysters to marketable size within 20-22 months, a time period within which loss to disease could be minimized. Truitt (1931) (Paynter et. al. 1992) showed that if oysters were lifted only a few inches off the bottom their growth rates could be increased by 50 to 100%. Paynter and DiMichele (1990) showed that oysters raised in floating rafts in a shallow tidal creek in Chesapeake Bay, exhibited very high growth rates (10-15mm/month).

In addition to increased growth rates, aquaculture techniques decrease losses from natural predation and storm washouts. Enclosed in mesh bags or string nets, large shellfish losses are uncommon. For example, the soft clam, Mya arenaria, has no upper salinity limit, but is restricted to mesohaline waters in nature because of high predation in higher salinities. Aquaculture can extend this natural limit of habitat.

Another important advantage of aquaculture is that it gives the culturist the opportunity to pick the site of operation. The aquaculturist can select the ideal operation site exhibiting optimal growing conditions and therefore produce a high quality product in a relatively short amount of time. Additionally, with the knowledge of origin, aquaculture production could possibly decrease consumer fears that the product may have come from unsafe waters and thereby help to rebuild their trust in the Bay's produce.

In addition to experiments investigating technical feasibility, studies addressing the economic feasibility of aquaculture operations in the region have also been conducted. Cost analysis studies indicate that aquaculture operations growing hard clams as well as the bay scallop appear to be promising (Paynter et al. 1992). Although the natural supply of the eastern oyster is at a record low for the region, the presence of MSX and Dermo presently makes oyster culture more of an economic challenge than the culture of the hard clam or bay scallop (Paynter, et al. 1992).

Although there are many legal and social obstacles still facing the expansion of aquaculture in Virginia (Neikirk 1990), it appears that with the new economic and ecologic incentives, many types of shallow water shellfish aquaculture could soon begin to expand in The Commonwealth's waters. Therefore, it is now time for resource managers to strategically plan and coordinate this new coastal use with the multitude of other coastal zone activities already under way.

III. MANAGING POTENTIAL USE CONFLICTS

A. Potential Use Conflicts Between Aquaculture and Other Uses

Potential use conflicts between aquaculture and other water uses may be relatively new in Virginia, but the issue has long been studied in other parts of the U.S. and other countries. The development of aquaculture can conflict with industry, navigation, riparian rights, traditional fishing rights, recreation, fresh water supplies and the preservation of natural resource systems (Pollnac 1992; DeVoe and Pomeroy 1992).

Studies addressing use conflicts between aquaculture and natural resource systems have focused mainly on the negative effects of fish/shrimp farming on nearby freshwater supplies, wetlands and mangroves (Pollnac 1992). For example, in the Philippines approximately fifty percent of the country's mangroves have been converted into brackish water fish ponds. This conversion not only destroys the mangrove ecosystem but indirectly causes negative impacts on surrounding systems. Significant changes in the hydrology of nearby land systems result from the loss of mangroves. Additionally the destruction of mangroves cause significant decreases in the production of organic detritus which is an important food source for nearby fish communities (Pollnac 1992). Also noted, was the possibility that deforestation can result from the huge amounts of wood needed to construct fish pens and cages. Once established, intensive fish farming can produce significant amounts of organic laden effluents which if not properly managed can severely pollute nearby systems. Additional problems can arise from the large amounts of food that are necessary to sustain the cultured fish. In Thailand; for example, certain fisheries have been exhausted in order to feed the cultured species (Pollnac 1992).

Potential use conflicts specifically between shellfish aquaculture and natural resource systems have received little attention. The destruction of SAV by the placement of old oyster shell in preparation for traditional on-bottom shellfish culture was documented (Bailley and Biggs 1958), but the majority of potential use conflicts between shellfish aquaculture dealt with navigation rights, riparian rights, traditional fishing, recreational and aesthetic concerns.

B. Minimizing Conflict Through Environmental Planning

Many of the use conflicts between aquaculture and natural resource protection could be minimized if properly managed in the early stages of development. Proper management begins with clear environmental planning (Joyce 1992), (e.g. the strategic sitting of aquaculture operations).

First, managers must study a region and determine all the areas suitable for the development of aquaculture operations and all the areas suitable for the habitat of the natural resource in question (in this case SAV preservation/restoration). The next step in the planning process, is to identify and delineate the optimal areas for each activity; in other words, "make meaningful comparisons about the suitability of different coastal areas" for each use (Brown and Hartwick 1988). This process of comparing site suitability not only optimizes production but aids in the development of coastal management policies (Brown and Hartwick 1988). Biophysical studies, for salmonid species and some shellfish species, have been carried out to provide sitting information for prospective aquaculturists. The information is intended to help them reduce the possibility of locating farms in unsuitable areas. (Dickson 1992)

Once the optimal areas for each use are identified and delineated, strategic management based on the environmental setting can be made.

The process of determining an area’s suitability for the survival of a specific species is based on the measurement of certain biophysical factors critical for the growth and survival of the species. The biophysical factors that are measured are unique for each species. Numerous studies have been undertaken to determine the environmental attributes that influence bivalve growth and to illustrate spatial heterogeneity in these attributes (Wilson 1987;

Paynter and Dimichele 1990; Incze et. al. 1980; Appeldoorn 1983). The Virginia Shellfish Task Force conducted a study in 1982 that attempted to rate areas according to their shellfish production potential. They chose biological and water quality related criteria to evaluate shellfish growing areas. The Task Force collected the data and made the calculations to rate the James River, the Lynnhaven Bay, the Piankatank River and the Rappahannock River. The Task Force believed that the results could be useful to "decision-making bodies" (Shellfish Task Force Report 1982).

The most commonly used technique of site evaluation is the Habitat Suitability Index (HSI) model. The HSI is defined as "the numerical index that represents the capacity of a given habitat to support a selected fish or wildlife species". (USFWS 1981). The U.S. Fish and Wildlife Service relies heavily on Habitat Suitability Index (HSI) models to determine the suitability of an area for a particular species. HSI models help managers in the assessment of environmental impacts as well as mitigation of resource use conflicts (USFWS 1980; Urich et. al. 1986; Brown and Hartwick 1988).

The HSI technique is generally comprised of two steps. First, a theoretical model of habitat requirements is constructed using existing information on species-environmental interactions (U.S. Fish and Wildlife Service 1980, 1981; Schamberger and Krohn 1982). Each requirement or ecological variable is measured at the study site and is rated according to a range of predetermined values for that variable. Once all the variables have been rated, their combined scores indicate the condition of the site. Generally a value of 0.0 indicates highly unsuitable habitat conditions and a value of 1.0 indicates optimal habitat conditions for growth and survival. After the model is created it is then tested in the field to verify its accuracy. The final step is not always executed.

A number of studies have used HSI models to determine the aquaculture potential of coastal areas (Brown and Hartwick 1988; Quayle 1971; Parsons 1974). The models were all based on critical variables affecting the growth and survival of the studied species. Brown and Hartwick (1988) constructed a HSI model for the suspended tray culture of the Pacific oyster using pre-existing information on the interactions between the organism and the surrounding environmental conditions. The habitat variables that they chose were water temperature, salinity, water movement, phytoplankton chlorophyll a, suspended sediments, disease, fouling organisms, predators, dissolved oxygen and pH. Brown and Hartwick's work was one of the first in which a model for suspended, subtidal culture was developed. Before this, most models dealt with intertidal culture rather the subtidal (Quayle 1971; Parsons 1974; Glude 1984). In another culture production model for the Pacific oyster, water temperature and available food were the primary HSI variables (Roland and Brown 1988). In 1983 Cake developed a HSI model for the American oyster (*Crassostrea virginica*). The model was verified in the field five years later by Soniat and Brody (1988). Cake's model is defined in terms of cultch availability, substrate firmness, mean water salinities, and mean intervals between lethal, freshwater floods. Models exist for many other marine bivalves such as little-neck clams (*Protothaca staminea*) (Rodnick and Li 1983), hard clams (*Mercenaria mercenaria*) and mussels (*Mytilus edulis*).

Habitat requirements for SAV restoration were recently established in the SAV Technical Synthesis (Batiuk 1992). Five requirements are listed as critical to SAV survival and minimal values for each requirement are given. These variables, detailed earlier in the SAV literature review, can be used to rate areas presently suitable for SAV restoration.

Once the critical parameters for a species are determined and their interactions modeled accordingly, the next step is to measure these biophysical variables at the study site to make comparisons of suitability. A number of techniques are used, some more accurate than others.

Biophysical measurements are taken *in situ* by traditional platforms and shipboard equipment. For example, in the Mainstem Water Quality Monitoring Program, the states of Maryland and Virginia conduct cruises on a regular basis to measure biophysical variables in Chesapeake Bay. The monitoring program includes approximately fifty stations. Although shipboard monitoring is the most commonly used method of collecting data, there are some disadvantages to this method. Because marine systems are dynamic, in situ surveys are restricted in time and space by expense and logistics. Localized events, such as algal blooms, may be under sampled or even entirely missed (Harding et. al. 1992). Modern techniques such as remote sensing from satellite and aircraft sensors can complement the in situ data to give a better picture of a system's dynamics (Harding et. al. 1992).

Once all of the biophysical data are determined using the methods described above, careful analysis of the spatial data is required to make meaningful management decisions. The Geographic Information System (GIS) is a state of the art data management system that allows managers to easily analyze and compare information. GIS is based on the concept of compiling layers of information for spatial interpretation. In the last few years GIS has been used for aquaculture and fisheries development (Ross et al. 1993). Ross and colleagues applied a PC-based GIS program to site selection for coastal aquaculture in Scotland. They first identified the main factors critical to salmonid cage culture from pre-existing literature. The parameters chosen where water depth, current speed, salinity, temperature and dissolved oxygen. The range and optimal values for each parameter were also determined. Using in situ surveys, the parameters were measured at the study site, Camas Bruaich Bruaich, Scotland. The data was then entered into the GIS program. A scoring system for each parameter was devised in order to rate sites according to their respective conditions.

Kapetsky and colleagues have conducted several studies using GIS and remote sensing to assess the potential of a given area for aquaculture development. Their findings demonstrate that GIS can be used to aid large area aquaculture development planning (Kapetsky et al. 1987; 1990).

GIS has the potential to provide useful results; however, it is important to note that the accuracy of the results depend on the data source (Ross et al. 1993). Even the best data sets often have temporal and spatial limitations. Mooneyhann (1985) has stated that "spatial modelling provides a more comprehensive and integrated treatment for aquaculture development than is usually possible by standard analytical and map-making technology" (Ross et al. 1993).

MATERIALS AND METHODS OF THE GIS SPATIAL ANALYSIS

Study Site: The Virginia portion of the Chesapeake Bay, and it's major and minor tributaries, were the regions chosen for this analysis (See Fig.1). The study site was divided into 14 segments for data averaging purposes (See Fig.2). The segmentation scheme used in this study was that developed by the Chesapeake Bay Program (CBP).

Computer Software and Hardware Used: The Geographic Information System (GIS) analysis was performed on a UNIX SUN SPARC Station using ARC/INFO software. The analysis was done at the Virginia Institute of Marine Science, Department of Coastal Resource Management and Policy, Coastal Inventory Laboratory.

The GIS spatial analysis consisted of several steps:

1)The development of a coverage rating each segment according to its site suitability for shellfish aquaculture. The site suitability was based on three biophysical parameters that strongly influence successful shellfish aquaculture: chlorophyll-a, current flow, and salinity.

2)The development of a coverage delineating the relative probability that SAV would occupy the Tier III restoration goal (basically the shallow water region from mean low water to two meter depth), throughout the study site (See Figure 4). This probability or likelihood of SAV occupancy was based on two data sets: distribution (past, present and potential) and surrounding water quality.

3)The comparison of coverage #1 and coverage #2 to identify areas of potential conflict, i.e. areas identified as having optimal aquaculture conditions as well as having a high probability of SAV occupancy from mean low water to 2 meters.

<u>Procedure Used To Develop The Shellfish Site Suitability Coverage:</u>

First, the digital shoreline topography for the study site was obtained from the Virginia Institute of Marine Science Coastal Inventory digital data base. The scale of the analysis was 1:1,000,000. Next, the segmentation scheme developed by the Chesapeake Bay Program was digitized and joined to the shoreline coverage using the GIS Arc/Info system. Finally, the average autumn salinity isohaline contour lines were digitized to scale and unioned to the shoreline/segmented coverage. This final coverage consisted of many polygons each having a label point (Fig 3.). GIS capabilities allow each polygon label to be coded for numerous attributes, ie. biophysical parameters. In this study the attributes coded for each polygon were chlorophyll-a, current flow, and salinity. These habitat parameters were chosen for this study based on their documented importance in the successful growth of cultured shellfish. Table (2) lists the tolerance ranges and in some cases the optimal ranges for each parameter for four commercially important species (oysters, hard and soft shell clams and bay scallops).

The average annual values of chlorophyll-a and maximum tidal velocities were calculated for each segment. The data used to calculate the average values were taken from pre-existing data-sets. The chlorophyll-a data consisted of median values measured during the critical life period of SAV (April-October) along 66 stations in the lower Bay. These data were gathered during the 1989 Chesapeake Bay Water Quality Monitoring Program for Virginia and Maryland. The maximum tidal flood data was obtained from the 1993 Tidal Current Tables - National Oceanographic Atmosphere Association (NOAA). A total of 128 stations supplied this data. The average autumn salinity gradients were obtained from Lippson (1973). Each polygon was coded for a salinity value (SAL = 5-30) depending on the salinity gradient into which it fell. Originally this study focused solely on oysters, and the autumn salinity gradients were used in the base coverage to identify the maximum upstream penetration of dermo and MSX. When the study was expanded, including clams and scallops, these gradients were not changed. In hindsight, spring salinities would have been much more appropriate as a general indicator of shellfish distribution. Fresh water flooding in the spring is the major limiting factor in the salinity distributions of shellfish (M. Luckenbach per. comm.). Once the average values of the parameters were calculated for all the segments, each polygon was coded according to two unique rating systems developed for this study (See Tables 3 and 4). Habitat Suitability Index models (HSI) and optimal ranges from the literature were used as the basis for these rating systems (See Table 2 for references). Each polygon received a numerical score ranging from 1 - 3, depending on what value range the average parameter value fell into. For chlorophyll-a conditions, a score of 1 indicates satisfactory conditions and a score of 2 indicates optimal conditions. For current speed conditions, a score of 1 indicated poor, a score of 2 indicated satisfactory and a score of 3 indicated optimal conditions. The chlorophyll-a scoring ranges for oysters and clams were based on Brown and Hartwick's 1988 habitat suitability work on the Pacific oyster. They listed a general food range for oyster growth between 1 - 55ug/L and listed 12ug/L plus as the optimal range. The majority of the literature indicated that both clam and oyster growth was best were food was abundant (Newell and Hidu 1982), therefore a general rating system was developed for both clams and oysters based on Brown and Hartwick's values (See Table 3). Brown and Hartwick's suitability graph indicated that growth was negatively influenced once chlorophyll levels reached 55 - 56ug/L. The highest average chlorophyll value for this study was 20.3 ug/L and therefore was well below the point of negative affects. The chlorophyll-a scoring range for scallops was based on the work of Kirby-Smith 1972, which found that growth can be stunted if chlorophyll concentrations are less than 1.2ug/L, but that growth is not positively affected by more. Therefore, any average chlorophyll value for a segment that was greater than 1.2 ug/L was scored the same. In this study all the segments had an average chlorophyll-a value larger than 1.2 ug/L. (See Table 5.) According to the majority of the literature on bivalve growth rates, oyster and clam growth rates were positively correlated with flow rates (Brown and Hartwick 1988, Newell and Hidu 1982, Rodnick and Li 1983, but see Grizzle et al. 1992 for an exception with oysters) whereas scallop growth rates were inversely proportional to flow (Kirby-Smith 1972). The scoring ranges for current flow were devised by equally dividing the range of current velocities measured within the study site. Three increments of 20.3cm/s were given a suitability score of either a 1,2 or 3. In the case of oysters and clams, the slowest current value range (0.1 - 25.4 cm/s) was given a score of 1 and the fastest value range (40.9-61.2 cm/s) was given a score of 3. The opposite scoring scheme applied to scallops (See Tables 3 & 4). See Tables 5 and 6 for average chlorophyll-a and maximum tidal velocity values per segment as well as their respective ratings.

Once coded for average chlorophyll-a, current flow and salinity, the coverage was unioned with an additional map which delineated the current distribution of the two oyster pathogens, Perkinsus marinus and Haplosporidium nelsoni. The coverages delineating disease prevalence were digitized from paper maps developed by the Biological Oceanography Department of the Virginia Institute of Marine Science (Burreson per.comm. 1993). Since the prevalence of oyster pathogens in the Bay area is very high, this factor cannot be overlooked in selecting optimal sites for oyster aquaculture.

Using ARCPLOT and the final coded coverge, a series of maps was produced. First, maps of the average distributions of chlorophyll-a and current velocities of the study site were produced along with a map delineating the average autumn salinity contours. Next, maps illustrating these same distributions were plotted with their appropriate ratings. Maps delineating the various combinations of available food, current flow and salinity ratings (poor, satisfactory and optimal) were constructed. Regions meeting the optimal criteria for both chlorophyll-a and current conditions and falling within the appropriate salinity range (See salinity ranges for each species in Table 7) were delineated as optimal aquaculture areas. Additionally, if an area within the appropriate salinity range had either an optimal chlorophyll-a or current rating and the other rated satisfactory, this area was delineated as an optimal aquaculture site as well.

Procedure Used To Develop SAV Site Suitability Coverage

A coverage was developed which predicted the likelihood of SAV occupying a given area within the shallow water habitat from mean low water (MLW) to a two meter depth. The base line of the coverage consisted of the digitized delineation of the Tier III restoration target goal (Fig.4). This potential habitat was then divided and rated according to past, present and potential SAV distribution trends as well as surrounding water quality conditions.

The SAV distribution rating was based on the present SAV distribution, the historical distribution of SAV in the 1960's and early 1970's, and the potential Tier III restoration target (MLW-2 meter contour). The present SAV distribution was delineated using the approximate 1989 distribution mapped by Orth and Nowack (1990). This general delineation was used to represent the present distribution of SAV in the Bay. There has been a net gain in SAV in the last three years, but changes have been small relative to the scale of this project. Areas in which SAV presently grow were coded PRES = 1 for potential use to occur.

The historical range of SAV was delineated using areas identified by Orth and Moore 1981 as regions where SAV was no longer present but had been very abundant in the late 1960's and early 1970's. The areas that fell within this historical range were considered to have a higher potential for SAV regrowth than areas outside of this range and were coded HIST = 1 for potential use conflict.

If the area was delineated in the Tier III target, but was not in the above two categories (present or historical), a code of 2M = 1 for potential conflict was given.

The second type of information addressed in the SAV coverage was that of water quality, more specifically the total number of SAV habitat requirements met per segment. Segments were rated according to the number of SAV habitat requirements met as of 1989.

Using data collected by the 1989 Chesapeake Bay Monitoring Program, the average values of the following SAV habitat requirements were calculated per segment: light attenuation (Kd), total suspended solids (TSS), chlorophyll-a (CHLA), dissolved inorganic nitrogen (DIN), and dissolved inorganic phosphorus (DIP) (See Table 1). Based on the calculated average values, each segment was rated on whether or not it could theoretically support SAV from mean low water to one meter as well as to two meters.

A segment was given an appropriate coded if the average values of four or more SAV one meter habitat requirements (1MHR) fell below their target values (See Table 1). In addition, a segment was given an appropriate code if its average light attenuation value was equal to or below the required value for two meter SAV restoration (See Table 1). See Table 8 for the segments that met the 1 meter and 2 meter habitat requirements. This information combined with the distribution ranges described earlier comprised the rating system that predicted the probability that SAV would be or would not be likely to occupy a particular segment of the study site (See Table 9 for the SAV rating system).

It is important to address several points concerning the reasoning and methodology behind rating the relative habitat suitability for SAV according to the number of criteria met in each segment.

1) In their natural settings organisms respond to a multitude of factors. Sometimes these factors are dependent on each other and complex formulas are needed to explain their interactions and sometimes these factors act independently. In the case of SAV in the Lower Chesapeake Bay the latter relationship was found (Batiuk 1992). The five major habitat requirements for growth chosen in the SAV Technical Synthesis (light attenuation coefficient, total suspended solids, chlorophyll-a, DIN, DIP) were found in general to act independently. No single habitat requirement by itself, however, was a perfect prediction of whether SAV would be present or absent. Nor was a single requirement consistently a better predictor of SAV's presence or

absence. The application of all five habitat requirements was found to be necessary in accounting for the reduction of light availability at the leaf's surface (Batiuk 1992).

2) Rating the segments of the Lower Bay by the total number of SAV habitat requirements met gives managers a method of identifying where SAV is most likely to grow or not to grow. This rating scheme was based on the findings of several case studies presented in Batiuk et al. (1992) which showed that the total number of habitat requirements met in an area was a good indicator as to the presence or absence of SAV. Statistics showed that 82% of the stations which supported SAV met four or five habitat requirements each year, whereas 79-83% of the stations which did not support SAV met three or less habitat requirements each year. Therefore the number of SAV habitat requirements met in a region appears to be a good indicator as to the likelihood that an area will or will not be inhabited by SAV.

RESULTS

ANALYSIS OF ECOLOGICAL MAPS AND OVERLAYS

RESULTS

The average chlorophyll-a distribution map (See Fig. 5) delineates the upper segments of the Rappahannock (TF-3, RET-3) and the James Rivers (TF-5, RET-5) as having an average chlorophyll-a value between 12.1-30.0 ug/L. The rest of the study site segments fell within the 1.0-12.0 ug/L range for chlorophyll-a concentrations.

The average maximum current velocities (See Fig. 6) fell between 20.5-40.8 cm/s for the segments on the western side of the Bay (CB-5, CB-6, WE-4), the lower segments of the Rappahannock (LE-3) and the James (LE-5) and the upper segments of the Rappahannock (LE-3). The rest of the study site, the eastern shore region (CB-7) and the middle and upper segments of the Rappahannock (RET-3), the York (LE-4, RET-4, TF-4), and the James (RET-5, TF-5), fell within the 40.9-61.2cm/s range for maximum current velocity.

The average autumn salinities are graphically illustrated in Fig. 7. The salinity range is delineated in gradients of five, starting at 5ppt. Segments (CB-7, CB-6, CB-8 and WE-4) have an average salinity of 20ppt and higher (polyhaline). The tributaries show a gradual decrease in salinity traveling up river away from the bay.

Once the appropriate score was assigned to a segment, the suitability for aquaculture sites based on the biophysical parameters could be identified.

Figure 8 illustrates the satisfactory and optimal sites for oyster aquaculture based on average chlorophyll-a concentrations. The analysis identifies the upper and middle segments of the Rappahannock (TF-3, RET-3), and the upper and middle segments of the James (TF-5, RET-5), as having optimal chlorophyll-a conditions. The remaining segments of the study site, the tributaries and the lower bay, fell within the satisfactory range for chlorophyll-a concentration. The same rating scheme used to rate chlorophyll-a conditions for oysters was used to rate chlorophyll-a conditions for hard shell clams and soft shell clams and therefore produced similar distribution maps (See Fig. 14, Fig. 19).

The site suitability for oyster aquaculture based on maximum tidal flood velocity (See Fig. 9), delineates the eastern shore segment (CB-7) and the middle and upper sections of each major tributary, with the exception of the upper tip of the Rappahannock (TF-3) as optimal conditions. The remaining segments in the study site, the western portion of the bay (CB-5, CB-6, WE-4), the upper and lower segments of the Rappahannock (TF-3, LE-3), and the lower James (LE-5) were identified as having satisfactory current flow. Again because the same rating scheme used to rate current conditions for oysters was used to rate flow for hard shell clams and soft shell clams, similar results were obtained and graphically illustrated (See Fig. 15, Fig. 20).

The general salinity range for oyster aquaculture is depicted in Fig. 10. The lower salinity end of this range is approximately 10ppt which typically falls in the mid to lower segments of the tributaries and extends into the polyhaline bay waters.

The hard shell clam can grow from 15ppt. to approximately 30-35ppt. This range begins in the middle to lower segments of the tributaries and extends into the bay (See Fig. 16). Soft shell clams have the widest salinity range of the shellfish studied, starting from 5ppt (oligohaline) and extending into the bay (See Fig.21). There is no upper salinity limit, but the presence of predators in high salinities restrict the soft shell clam to mesohaline waters.

By combining the rated distribution maps of chlorophyll-a, current velocities, and salinity ranges for each shellfish, the overall site suitability maps were developed. Figs. 11, 17 and 22 illustrate the various combinations of chlorophyll-a distribution, tidal current velocities and salinity ranges for the oyster, the hard shell clam and the soft shell clam respectively. Eight combinations were possible. The two most suitable combinations of chlorophyll-a, current velocity and salinity were selected:

1. Sat.Food/Opt.Current/Suit.Sal
2. Opt.Food/Sat.Current/Suit.Sal

The polygons which matched these combinations were delineated in order to identify segments ideal for shellfish aquaculture. The results indicate that the optimal sites for oyster aquaculture, according to this rating system, lie along the Eastern Shore (Segment CB-7) and the middle segment of the Rappahannock (RET-3) and the lower section of the York River (LE-4) (See Fig. 12). When determining site selection for oyster culture, it is essential to identify the distribution of the two oyster pathogens, *Perkinsus marinus* and *Haplosporidium nelsoni*, present in the Bay. Figure 13 delineates the distribution of these parasitic protozoans and overlays this delineation with the optimal sites for oyster aquaculture. There is almost a complete overlap of areas well suited for culture and areas affected by the pathogens.

Scallop growth is stunted if there is less than 1.2 ug/L of chlorophyll-a but not positively affected if more is available (See Table 2). Since the lowest segment value of chlorophyll-a was 1.3 ug/L, all the segments received an optimal score of 2 (See Figure 24).

The site suitability for scallop aquaculture based on average maximum tidal velocity (See Fig. 25) delineated the Eastern Shore (CB-7) and the middle and upper segments of the major tributaries (RET-3, LE-4, RET-4, TF-4, RET-5 and TF-5) as poor conditions for bay scallops. This is the inverse rating these same segments received using the rating scheme devised for oysters, hard clams and soft clams. The reason for this difference in rating lies in the fact that the scallop's growth rate is inversely proportional to current speed (Kirby-Smith and Barber 1974). The remainder of the study site, the western portion of the Bay (CB-5, CB-6 WE-4), the lower Rappahannock River (LE-3), the lower James River (LE-5) and the upper segment of the Rappahannock River (TF-3) all rated satisfactory based on current conditions.

The general salinity range for bay scallops was designated as 20ppt and higher. This range encompasses the lower tip of segment LE-5 of the James River, the Mobjack Bay (WE-4) and most of the mainstem of the Bay (CB-6 and CB-7) (See Fig.26).

Figure 27 indicates the various combinations of suitability conditions rated for bay scallops. A total of four combinations were possible: Optimal food combined with either poor or satisfactory tidal velocity and located inside or outside the predetermined salinity range.

Figure 28 highlights the polygons having the ideal of the four combinations: Opt.Food/Sat.Current/Suitable Salinity. The region is comprised of the western portion of the Bay and Mobjack Bay (CB-6) and (WE-4). The lower tip of the James River (lower part of segment LE-5) is also included.

The probability, based on distribution trends and surrounding water quality, that SAV will inhabit an area from mean low water to the 2 meter contour is graphically illustrated in Figure 29. The highest probability was identified along the Eastern Shore region. The western portion of the Bay, including the Mobjack Bay and lower segment of the Rappahannock was delineated as high probability. The middle section of the Rappahannock (part of LE-3 and RET-3) registered moderate/high and moderate/low. The lower segment of the York River (LE-4) received ratings of moderate/high and low probability. The remaining segments of the Bay (RET-4, TF-4, RET-3, TF-3, LE-5, RET-5 and TF-5) all received the lowest probability rating.

When Figure 29 was overlaid with the optimal sites for oyster and scallops, the following results were produced. Optimal aquaculture sites for oysters along the Eastern Shore fall within the highest SAV restoration probability region (CB-7). In the Rappahannock River the optimal oyster culture sites overlap with moderate/low and lowest probabilities. In the York River optimal oyster culture sites overlapped with high, moderate/high and low probability areas (See Fig. 30). Optimal scallop culture conditions exist in the western portion of the Bay and the Mobjack Bay. These areas lie within regions designated as SAV restoration high probability (See Fig. 31).

CONCLUSIONS/DISCUSSION

CONCLUSIONS/DISCUSSION

A.DISCUSSION OF SPATIAL ANALYSIS:

Based on this analysis, both the areas displaying optimal conditions for aquaculture operations and the areas displaying suitable conditions to support SAV restoration have been identified and delineated. The results of this environmental analysis set the basis for strategic management and planning. Not only can this planning minimize conflicts between aquaculture development and SAV regrowth but will also optimize aquaculture production.

The aquaculture site suitability analysis based on food, current speed and salinity, suggests that oysters and clams should be grown in the middle section of the Rappahannock (RET-3), in the lower section of the York river (LE-4) and on the eastern shore of the Bay (CB-7). This distribution fits the general pattern of where these animals are presently being grown. Suitable areas for bay scallops are identified on the western shore (WE-4) and the lower portion of the James river (LE-5). This distribution does not fit the general trend of where scallops are presently being grown. Currently, the only area where bay scallops are being successfully cultured in Virginia is the seaside of the Eastern Shore. The reason, for these differences, most likely lies with the salinity value range chosen for bay scallops, this value range should be closer to > 25 ppt, not >20 ppt. Another factor, affecting the accuracy of the bay scallop distribution results, is most likely the use of autumn salinities and not spring salinities. The use of autumn salinity gradients erroneously delineates shellfish distributions. For example, according to autumn salinity gradients, readings of 20 ppt are found at Gloucester Point, VA. (Lower section of the York River), in contrast to spring salinity gradients which place this same value near the lower end of the Eastern Shore. Fresh water floods can be lethal to shellfish and therefore spring salinities should be used in further studies to delineate the areas of lowest tolerance.

The areas with the highest probability of SAV meeting the Tier III target, and therefore the highest degree of potential use conflict with shallow water aquaculture lie on the eastern Shore (CB-7), the western Shore (WE-4) and the lower tributaries of the Rappahannock (LE-3) and the York (LE-4).

To minimize use conflict between SAV restoration and shallow water aquaculture development, managers need to encourage the placement of shellfish culture operations in optimal sites that do not fall within areas rated moderate/high or higher for SAV restoration. The entire mid-section of the Rappahannock (RET-3) and the upper tip of section LE-4 of the York were identified as optimal areas for aquaculture and do not fall within the areas with a high probability of 2 meter restoration. Recent studies have shown that tray and rack aquaculture operations located in 10-12 ppt have successfully yielded quality oysters in relatively short time periods. At this salinity, the overall prevalence of disease is less and therefore gives the oysters a better chance of survival. The tray and rack method also speeds the oyster's growth rate and therefore increases survival. The oysters are then transferred to an area with higher salinity such as Mobjack Bay for a limited time. Here the oysters continue to grow and also acquire the salty taste consumers demand. The oysters are only kept in higher salinities for approximately 4-6 months. This brings the total time required to grow the oyster to marketable size within 1.5 years, which increases the oyster's chance to beat the diseases that usually strike in the second summer.

Operations for oysters and soft shell clams should be emphasized in the shallow waters of the upper and middle sections of the Rappahanock and York rivers and restricted or limited in the shallow waters of the Bay and the lower segments of the tributaries. Hard clam operations should be encouraged in the shallow water regions of the middle and lower York and restricted or limited in the shallow waters of the Bay and the lower segments of the tributaries.

Since the optimal areas for bay scallop aquaculture, delineated by this analysis do not appear to be sound, management suggestions for the strategic placement of bay scallop operations will not be made in this analysis. A new spatial analysis including the seaside of the Eastern Shore should be developed in order to strategically minimize conflict between bay scallop operations and the preservation/restoration of SAV.

B. LIMITATIONS OF THE ANALYSIS

This study was originally intended to produce a more refined analysis of resource distribution potential, delineating the relative suitability of adjacent creeks and inlets for aquaculture. Due to the spatial and temporal limitations of the data-sets available research has been necessarily limited to a general comparison of large segments of the Bay and its tributaries. This methodology, comparing relative site suitability of large areas, was similar to the methodology used by the Virginia Shellfish Task Force in 1982 when they conducted an evaluation of potential shellfish areas in the James River, the Wicomico River and the Lynnhaven Inlet (Interagency Task Force on Shellfish Resources 1982). With the development of a more complete shallow water data set for the region, as well as new high speed mapping and simulation modeling techniques, a more refined and accurate analysis can be executed.

B.1 <u>Spatial</u> <u>Limitations</u> A total of 66 water quality monitoring stations are located in the study area, the Virginia portion of the Chesapeake Bay and its tributaries. It was from these data that the growing season median values for light attenuation, chlorophyll-a, TSS, DIP, and DIN were obtained. With the study area divided into 14 segments by the CBP's segmentation scheme, the average number of monitoring stations per segment was approximately five. The tidal current data obtained from the Tidal Current Tables

1993 NOAA, was collected from 128 stations within the study area. Again, considering the 14 segment division, there were approximately 9 tidal stations per segment. The number of stations per segment was extremely small and did not allow for a fine scale analysis.

In addition to the small data-set, the majority of the monitoring stations fall within the deep mid-channel waters not the shallow bottom areas on which this study focuses. Extrapolation of the tidal data was attempted but with limited shallow water values a refined analysis of shallow regions was impossible (See Fig. 32). In Figure 32 for example, Mobjack Bay and adjacent shallow water are delineated as the same value. Instead of extrapolating chlorophyll-a and tidal velocity data, the average seasonal values for these parameters were calculated per segment. The decision not to extrapolate can be further supported by the large value ranges found within the Bay waters (See Table 10). With wide value ranges such as these and a sparse data-set, site specific delineations were not justified.

B.2 <u>Temporal Limitations</u> Ecosystems are dynamic. Any attempt to map or delineate a ecosystem's dynamic condition will fall short of describing the system by the mere fact that the map is only portraying a short period in time. Seasonal averages do not convey the stochastic events that affect certain areas of the system.

A dynamic model made from an extensive shallow water data-set, including all of the important habitat variables, would be the ideal technical tool for the potential conflict analysis described in this thesis work. Models of this type for biophysical parameters such as chlorophyll-a and current velocities are presently being developed.

B.3 Additional Limitations In addition to the spatial and temporal limitations of the data set used, several shortcomings in the creation of the scoring system for the three biophysical parameters may affect the accuracy of the results for the aquaculture site suitability analysis. Broad scaling ranges were used to rate parameter values and the scores were treated independently. The parameters scores were merely added, given equal importance. In the natural setting these parameters interact, and are therefore dependent. A more interactive and detailed habitat suitability scoring system should be stressed, once more detailed data sets are available. Also, due to new findings in flow and feeding studies of non-siphonate bivalves (oysters and scallops), the scoring system for current flow will need appropriate adjustments. Finally, spring salinity gradients should be used in further analyses instead of autumn salinity gradients in delineating salinity distribution.

This study is an effort aimed at allowing managers to proactively minimize use conflict with the most accurate knowledge base presently available. Although the data sets had spatial and temporal limitations, they were the best that could be obtained. Some scientists would argue that better data sets should be developed before proceeding with an analysis like this. However, many management programs wait years before addressing the potential conflict until the exact data have been collected and end up wasting precious time and natural resources in the delay.

Although a fine scale analysis was not possible in this study, the spatial analysis obtained does reveal general trends and distribution overlaps between shallow water aquaculture and SAV from which managers could begin to base decisions. If future studies draw new conclusions, then managers can adjust earlier plans.

This work also provides an exercise in analyzing a resource management concern with the most accurate preexisting information available. Either a complete accurate data set exists (the ideal situation) or a complete accurate data set does not exist. If the later situation occurs there are several possible scenarios:

1. Some data for the desired variable exists and it might be possible to extrapolate these numbers, using basic modeling, to give general trends of the variable under question.
2. No data for a given variable exits but some other variable that indirectly illustrates general trends of the desired variable is available and is used.

3. No data or related data are available and research to obtain this information should be set up as soon as possible to provide the manager with the proper tools to evaluate the situation. This is an example of how management needs can guide scientific research.

C. MANAGEMENT AND POLICY RECOMMENDATIONS

Given the general results and known limitations of the this analysis, management decisions should not be based solely on these findings. However, when used in conjunction with today's site-by-site method of permitting this analysis can provide valuable insight to managers and act as a guideline for the proactive placement of activities. If extensive data sets and modelling were incorporated into this spatial analysis protocol, a more detailed management plan could be developed toward the ultimate goal of differentiating conditions of adjacent shallow water regions at a very fine scale. Policy, ie. zoning, at the state and local levels could be developed based on the refined results.

Based on the general findings of this study, it is recommended that the following management directions be seriously considered when positioning shallow water aquaculture operations in the lower bay.

In areas identified as having the lowest restoration probability (TF-3, TF-4, TF-5, RET-4, RET-5, LE-5), <u>unrestricted</u> aquaculture development applies. Operations can be established wherever optimal conditions exist. Shellfish with high filtering capacity (oysters and soft shell clams) should be concentrated in these areas in order to promote improved water quality and light penetration.

In areas identified as having low, moderate/low and moderate/ high SAV restoration probability (portions of LE-3, LE-4, RET-3), limited aquaculture development applies. Operations should be strategically established (ie., adjacent growth) in the shallow water zone measuring from 1 meter to 2 meters deep. Some operations may need to be moved to deeper waters as water quality improves and SAV begins to grow in the 1 - 2 meter zone.

In areas identified as having high and highest SAV probability (CB-7, CB-6, WE-4, and portions of LE-3, LE-4), prohibition is suggested. No new aquaculture operations should be established within shallow waters with the possible exception being operations under existing or otherwise permitted docks. Intertidal and deeper water operations should be emphasized.

The author based the above management directions on the high priority that SAV has been given in recent policy (See Background / Literature Review for more details). Policy on aquaculture in Virginia is lacking at present and several steps must be taken to aid the development and management of aquaculture if it is to be successful in the Commonwealth.

A number of regulatory changes must be addressed before aquaculture can develop to its full potential in the Commonwealth. First, the process of obtaining a permit and lease for the aquaculture site is costly and time consuming. In a recent survey of 23 coastal states, 19 states reported having so-called "traditional" shellfish lease programs, while only 12 reported having adopted "contemporary" aquaculture leasing mechanisms (DeVoe and Mount 1989). The shellfish leasing program in Virginia falls under the category of "traditional" shellfish lease programs. The slow, expensive process dissuades many potential small scale operations. The recent modification of Regional Permit #19 is an important step in speeding up the permitting process for small operations (See Lit. Review for more details). Second, restrictions created for traditional harvesting (seasonal, size, gear and residency status) are not suited for aquaculture's unique differences, yet still apply to the new industry. Finally, unlike states with successful aquaculture programs, Virginia's laws presently do not allow for the leasing of the water column. This restriction impedes the establishment of the trays, racks, and cages that off-bottom shellfish aquaculture employs. Virginia may want to consider what other coastal states have done in terms of not only leasing the bottom but also leasing the water column. In North Carolina for example, a new law was recently passed that allows culturists to lease the water column. The leasing fee however is $500.00 per acre, a price that may dissuade smaller operations. In Florida, culturists are allowed to use up to 12 inches of the water column without purchasing an expensive lease (Edgerton 1992).

D. MAGNITUDE OF POTENTIAL USE CONFLICT BASED ON ECONOMIC DEMAND

To foresee the potential magnitude of the use conflict, it is necessary to predict the possible success and therefore expansion of shallow water shellfish culture in the state of Virginia. An important question to be addressed is, "what is the present and potential market (demand) for shellfish cultured in Virginia"? This question is not easily answered due to the following reasons:

1.)Predicting the future market demand for any product is an extremely complex process which involves many factors. Economists have developed detailed models to predict a product's demand potential.

2.)Data for cultured shellfish, with the exception of clams is lacking. For example, because oyster culture in the state of Virginia is a very young industry there are inadequate data available to develop a predictive market demand for this business. It is difficult to separate data from cultured oysters and data collected from natural stocks. An annual survey would be useful to collect data on acreage under culture, the amount of oysters harvested and the price. (Joint Subcommittee on Aquaculture 1983).

For the reasons listed above no attempt is made to calculate the exact demand of cultured shellfish in Virginia. Rather, possible scenarios of future demand are presented along with calculations of the associated space necessary to meet these demands. Future economic studies will be necessary to ensure that the most accurate data are being used by managers in decision making processes concerning the relative extent of shellfish aquaculture.

Although predicting future demand for cultured oysters is complex, one simple but paramount trend is evident to managers, scientists, economists and the public. Natural harvest levels of the American oyster in the Chesapeake Bay have reached record lows. The Chesapeake Bay area (Maryland and Virginia) formerly produced half of the oysters in the country but in the 1980's produced only a little over 1/3 (Menzel 1991). The Chesapeake Bay produced more than 32 million pounds of oysters annually until about 1959 when a sharp decline began. By 1989 only 4 million pounds were harvested from the Bay, and in 1990 this dropped further to 3.7 million pounds (The 1990 National Shellfish Register of Classified Estuarine Waters). Harvest from the Gulf of Mexico, in contrast, has shown a fairly steady increase, now accounting for over half the harvest in the United States. However, even with the Gulf states increase in harvest levels, increases in imports are necessary to counterbalance decreases in total U.S. productions (The Joint Subcommittee on Aquaculture 1983). An estimate from the literature predicts an increase in consumption of oysters in the U.S. from 34,100 metric tones (75 million lb.) in 1970 to 56,820 metric tones (125 million lb.) by the year 2000. With these general trends in mind, it is easy to appreciate the great potential that aquaculture could have in the near future.

The goal of this section is to theoretically create the optimal future market for the Virginia oyster if it were solely supplied by aquaculture methods. This exercise is a simplistic attempt to obtain a theoretical demand cap or ceiling for the young market. Using this number as a theoretical best scenario, the acreage necessary to produce this harvest could easily be calculated by knowing the number of oysters that can be grown with X amount of space (hectare). This acreage value is important to know because it provides managers with an estimate of the potential space that oyster culture could theoretically occupy. In relation to the ecological overlap investigated in the spatial analysis, does this potential acreage value create a relatively small or large usage conflict? The best scenario value was obtained by reviewing the historical market landings of the Virginia oyster in the last century and choosing the maximum recorded value. Several values between this high and the present low value were used also to calculate additional potential use scenarios.

Off-bottom culture studies have indicated that 0.1 ha (0.25 acre) covered by rack cultures could yield 2.6 metric tons (2.9 ton) (5,800 lbs.) of oysters per year. Yields could vary depending on such factors as productivity of the waters and total flow. (The Joint Subcommittee on Aquaculture 1983). The size of an oyster culture operation in Virginia is approximately 4 to 6 ha (10-15 acres) (Joint Subcommittee on Aquaculture). Based on this average operation size and the potential yield listed above, the numbers of typical Virginia aquaculture operations (5ha) needed to produce several different harvest yields were calculated. These calculations provide predictions of the magnitude of potential overlap between SAV and aquaculture operations.

Table 11 lists several dates and the amount of oyster meat that was harvested for that particular year and the number of hectares that would be required to grow this amount of meat using the figures cited above from the National Aquaculture Development Plan.

To give managers some idea of the relative magnitude of potential conflict, the target number of hectares (the 2m restoration goal) for three tributary segments (LE5, LE4, RET3) were compared to the number of hectares calculated in Table 11. The total SAV target number of hectares for segments LE5 LE4 and RET3 is 24,591. By using 20% of this total number, approx. 4,918 hectares, for aquaculture rack operations, theoretically 245 five hectare plots could be set up with 15 hectares of SAV growing between operations. The number of hectares placed between operations is arbitrary and the calculations could be made with a smaller or larger space between operations. Approximately 14.3 million lbs. of oyster meat could theoretically be produced from this scenario. To produce the 46.3 million lbs. of meat as harvested in 1880, it would take approximately 800 hectares of space. If this total space was multiplied by 15, assuming 15 hectares of SAV between operations, this would require 12,000 hectares of adjacent growth, half of the total target goal (24,000).

FUTURE RESEARCH

FUTURE RESEARCH

Future scientific research is needed to help answer critical ecological and aquaculture engineering questions. The results may help managers develop a clearer understanding of the dynamics between the two resources.

Adjacent growth experiments need to be conducted in order to study the potential positive effects the two resources might have on each other. Some researchers believe that with an added source of neighboring shellfish, filtering the surrounding water, SAV in the adjacent water column would prosper due to decreased turbidity and increased light penetration. Studies determining the validity of this hypothesis and quantifying the numbers of shellfish needed to accomplish this effect are crucial in answering this question. It is important to remember that the SAV beds, in turn, reduce suspended sediments from the water, thereby removing unwanted sediment particles that interfere with filter feeding shellfish. Juvenile clams can actually be smothered by siltation (Funderburk 1991). Another possible benefit of adjacent growth could be the potential buffering effect of wave energy by long lines of floating or suspended racks and trays. If strategically positioned, lines of trays might turn naturally high energy areas into suitable SAV habitat.

The development of experimental rack structures that will not destroy SAV growing underneath is a topic which deserves attention. Andrew Teeling, a Virginia aquaculturist is employing an experimental "rotating" rack structure. The idea behind this system is that the rack is not constantly blocking out light in a given area. The rotating system might allow some SAV growth in the aquaculture area that would otherwise be destroyed by the traditional rack system through shading.

An intensive look at the potential economic demand for cultured shellfish products is also necessary to predict the extent of aquaculture development. Predictions of the potential space necessary to cultivate given yields of hard clams, soft clams and mussels should be made.

Extensive shallow water data sets are lacking in Chesapeake Bay research. In order to develop an analysis with fine scale resolution, detailed shallow water monitoring programs should be developed. This study is a good example of how management needs can direct scientific research. Along with improved data sets, sound models should be developed to best portray the dynamic shallow water ecosystem.

FIGURES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

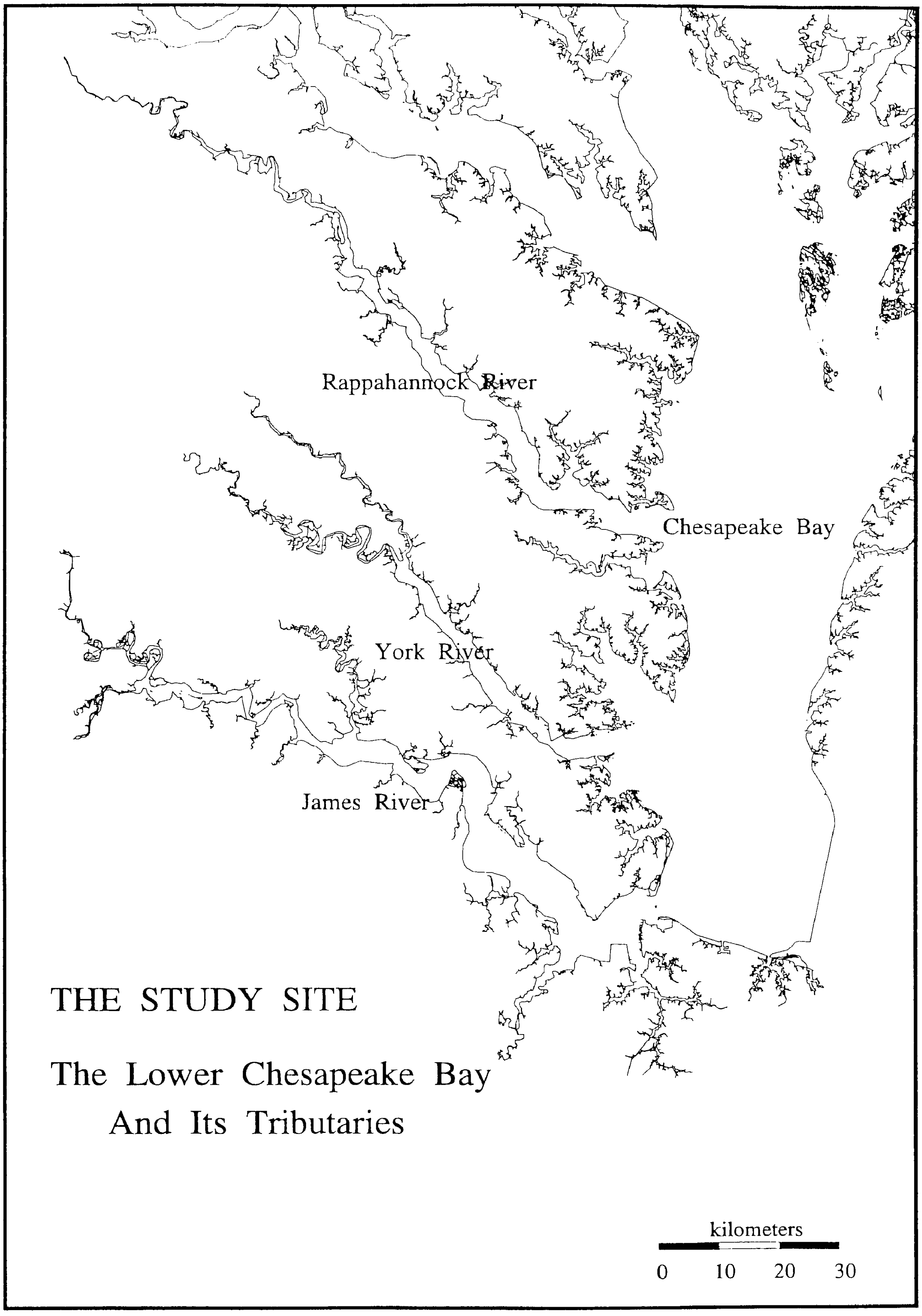

Rappahannock River
Chesapeake Bay
York River
James River
THE STUDY SITE
The Lower Chesapeake Bay
And Its Tributaries
kilometers
0 10 20 30

Fig. 1

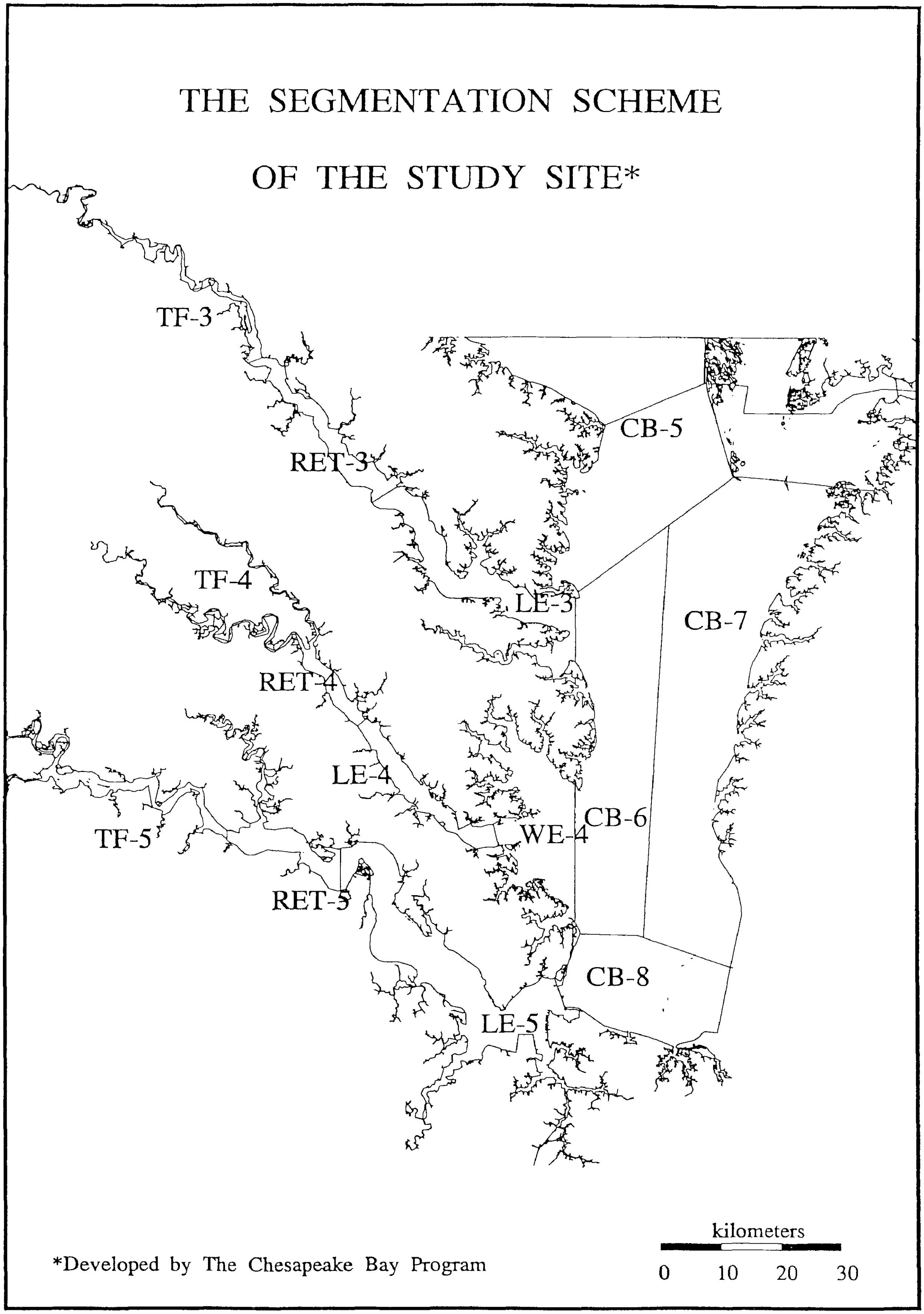

THE SEGMENTATION SCHEME
OF THE STUDY SITE*
TF-3
RET-3
CB-5
TF-4
LE-3
CB-7
RET-4
LE-4
CB-6
WE-4
TF-5
RET-5
CB-8
LE-5
*Developed by The Chesapeake Bay Program
kilometers
0 10 20 30

Fig. 2

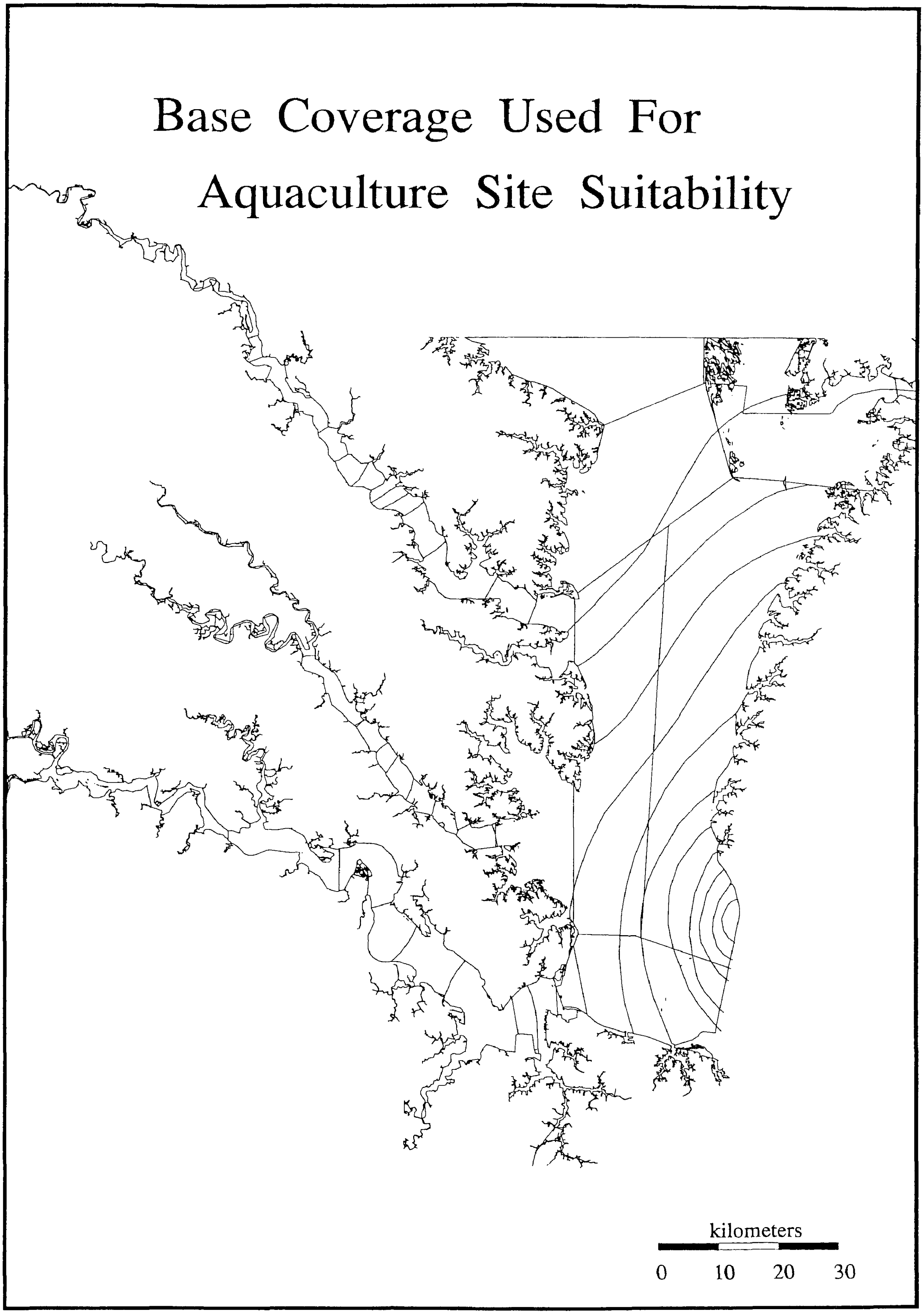

Base Coverage Used For
Aquaculture Site Suitability
kilometers
0
10
20
30

Fig. 3

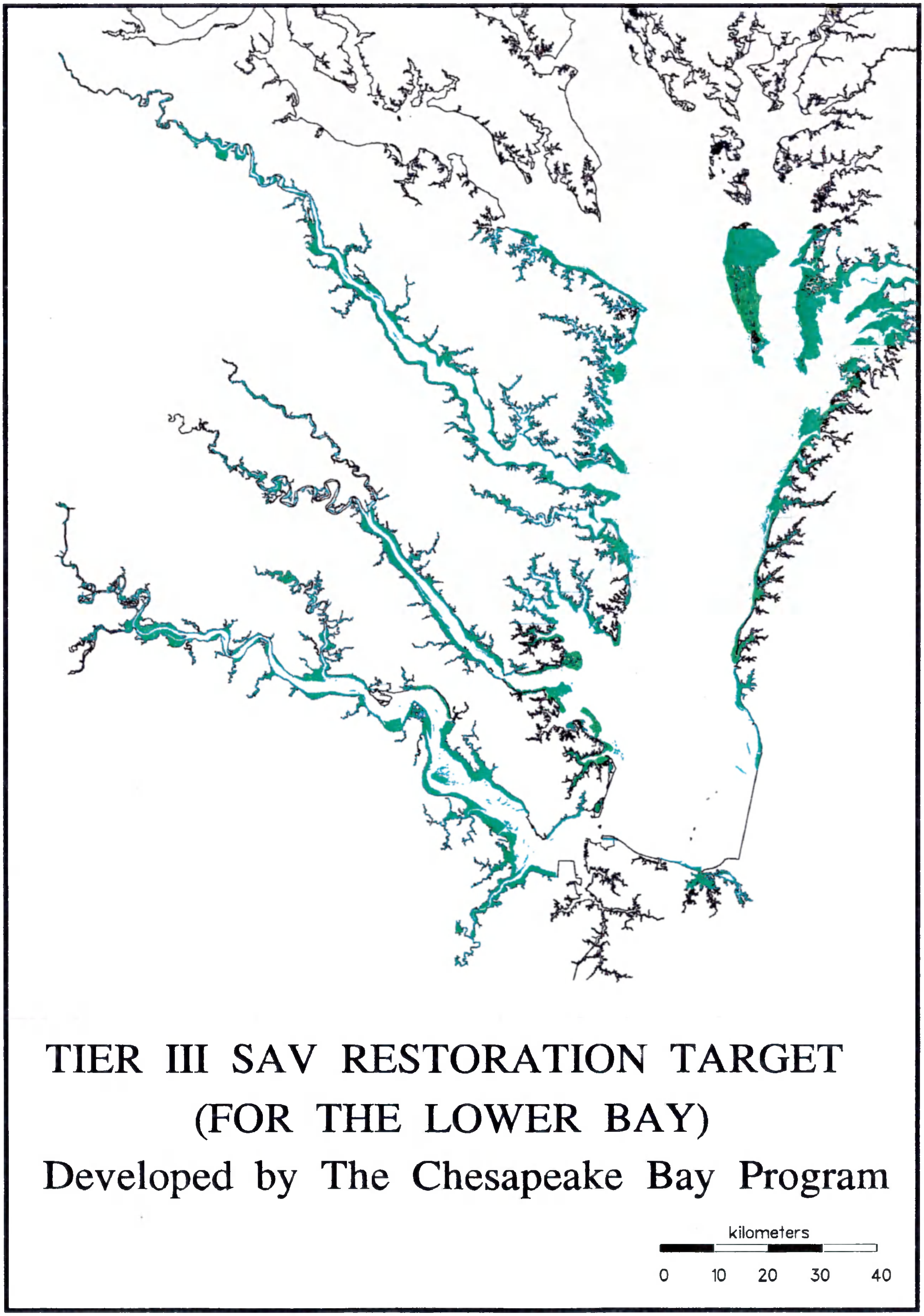

TIER III SAV RESTORATION TARGET
(FOR THE LOWER BAY)
Developed by The Chesapeake Bay Program
kilometers
0 10 20 30 40

Fig. 4

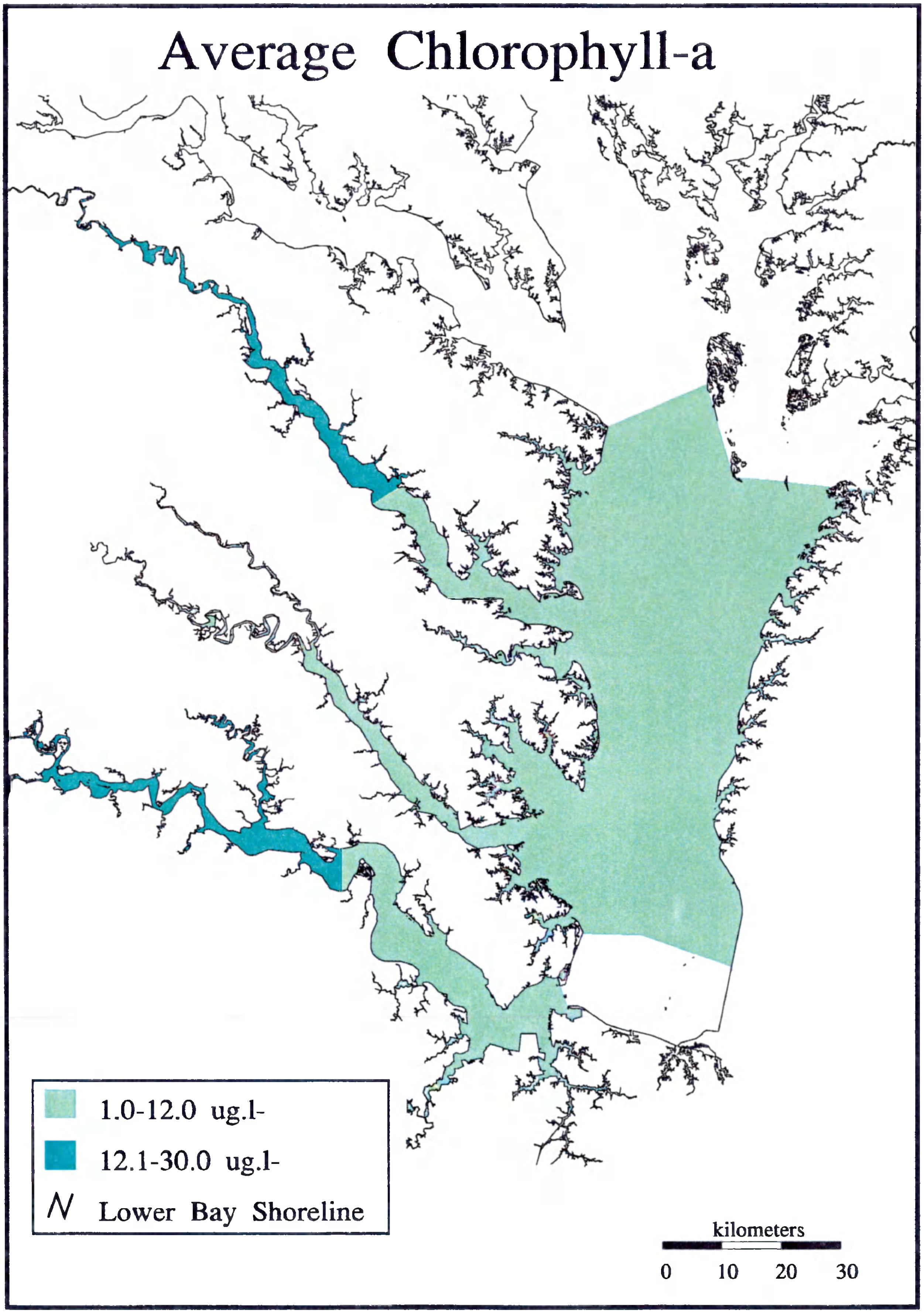

Average Chlorophyll-a
1.0-12.0 ug.l-
12.1-30.0 ug.l-
Lower Bay Shoreline
kilometers
0
10
20
30

Fig. 5

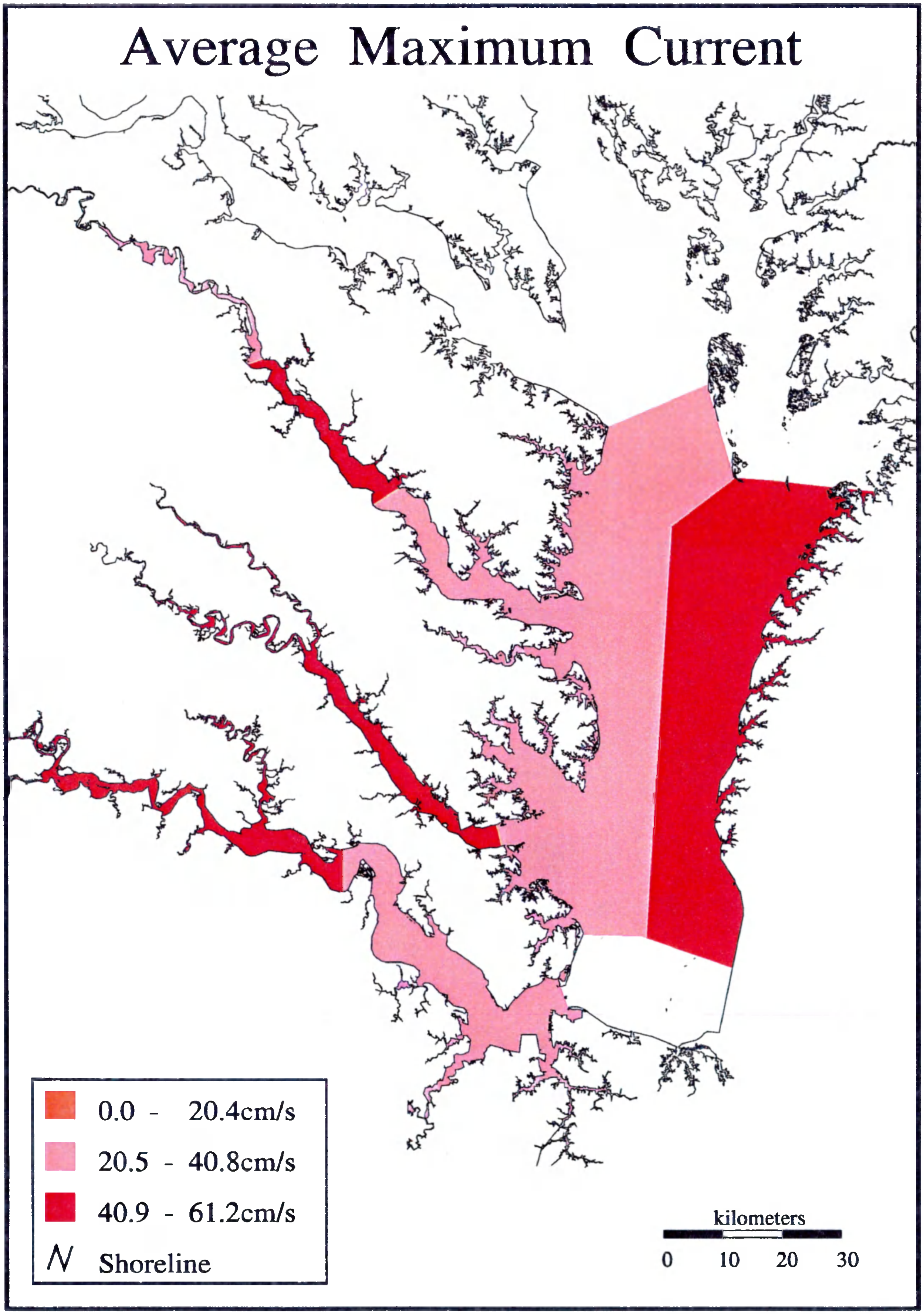

Average Maximum Current
0.0 - 20.4cm/s
20.5 - 40.8cm/s
40.9 - 61.2cm/s
Shoreline
kilometers
0
10
20
30

Fig. 6

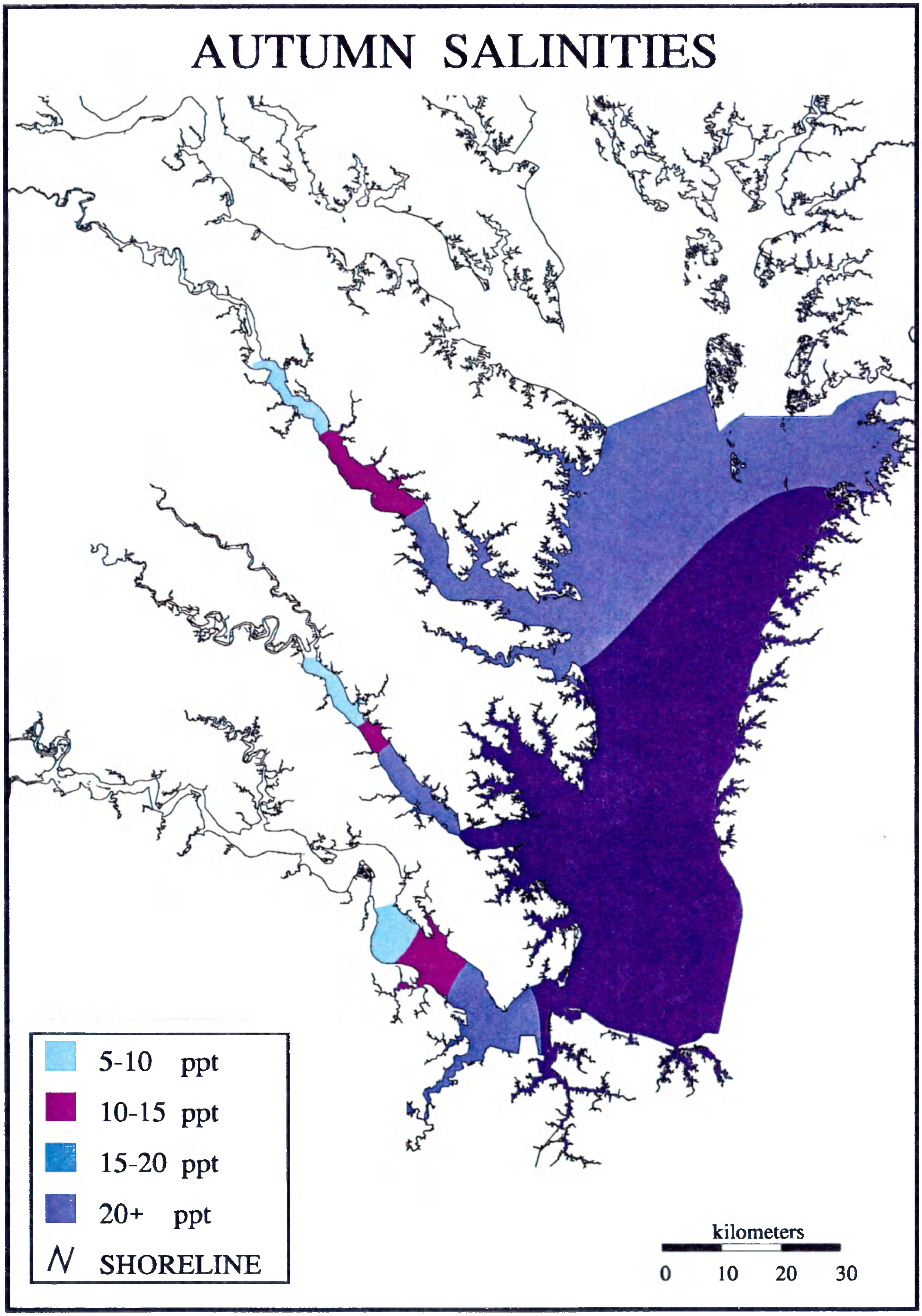

AUTUMN SALINITIES
5-10 ppt
10-15 ppt
15-20 ppt
20+ ppt
SHORELINE
kilometers
0 10 20 30

Fig. 7

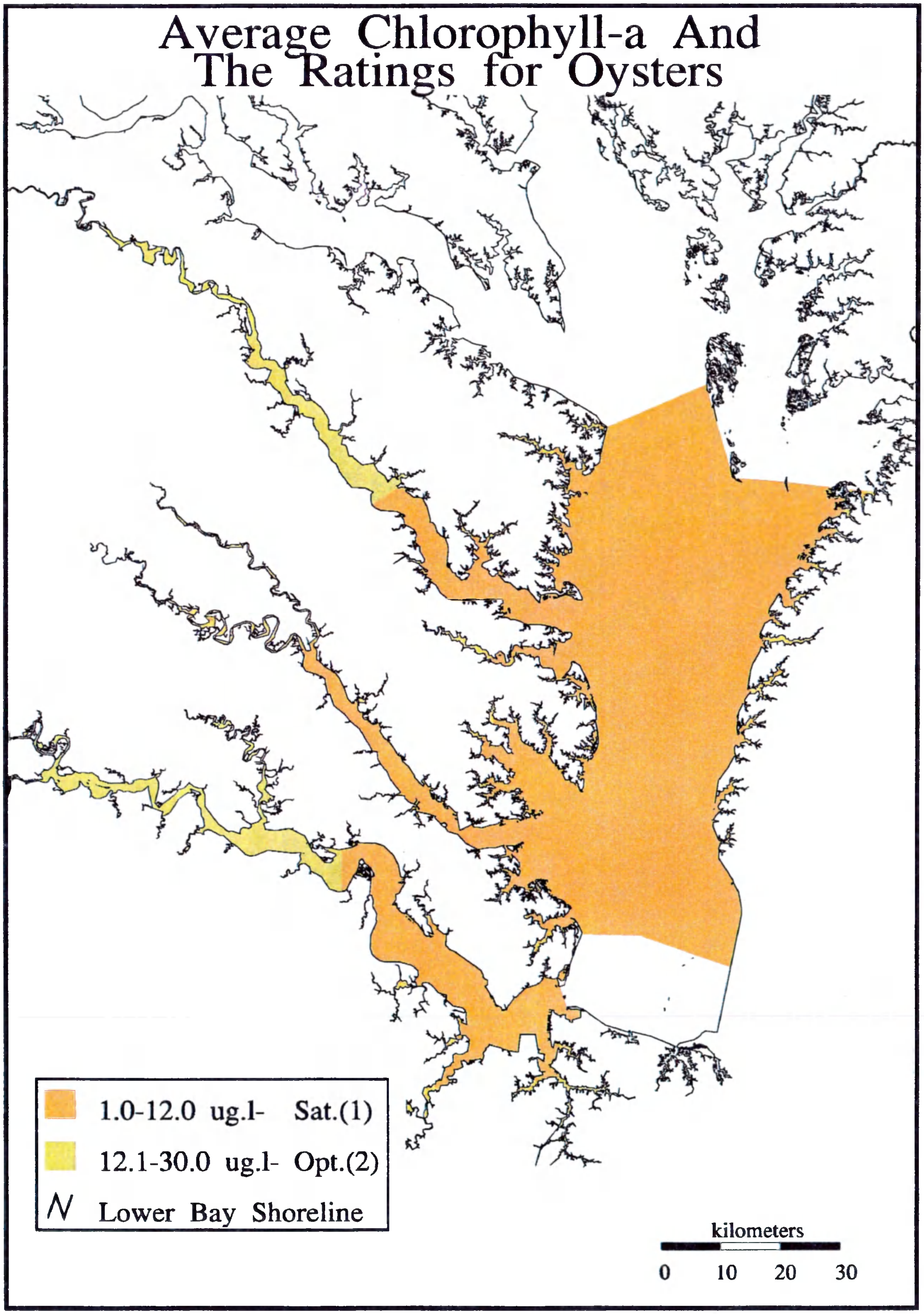
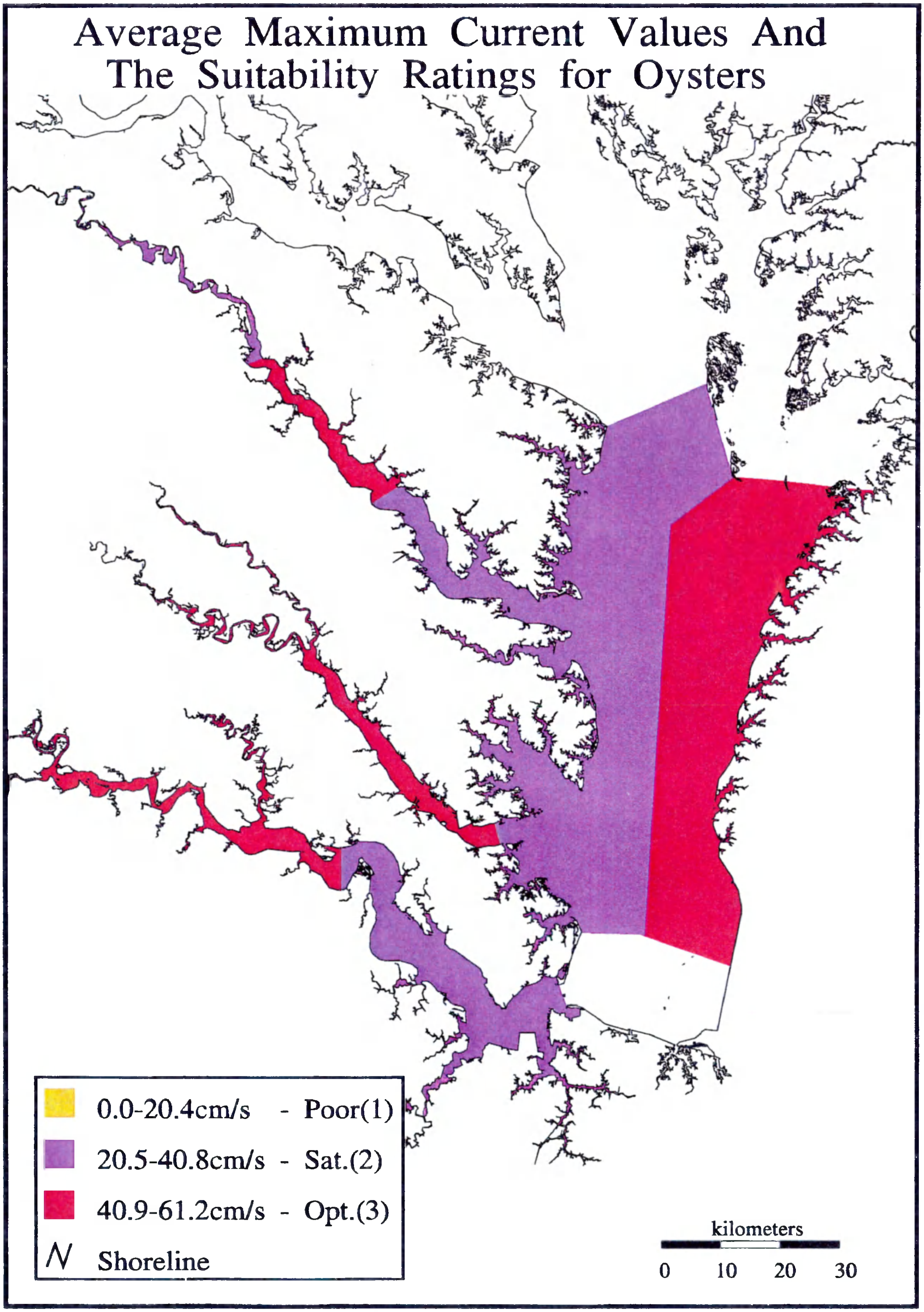

Average Chlorophyll-a And
The Ratings for Oysters
1.0-12.0 ug.l- Sat.(1)
12.1-30.0 ug.l- Opt.(2)
Lower Bay Shoreline
kilometers
0 10 20 30

Fig. 8



Average Maximum Current Values And
The Suitability Ratings for Oysters
0.0-20.4cm/s - Poor(1)
20.5-40.8cm/s - Sat.(2)
40.9-61.2cm/s - Opt.(3)
Shoreline
kilometers
0
10
20
30

Fig. 9

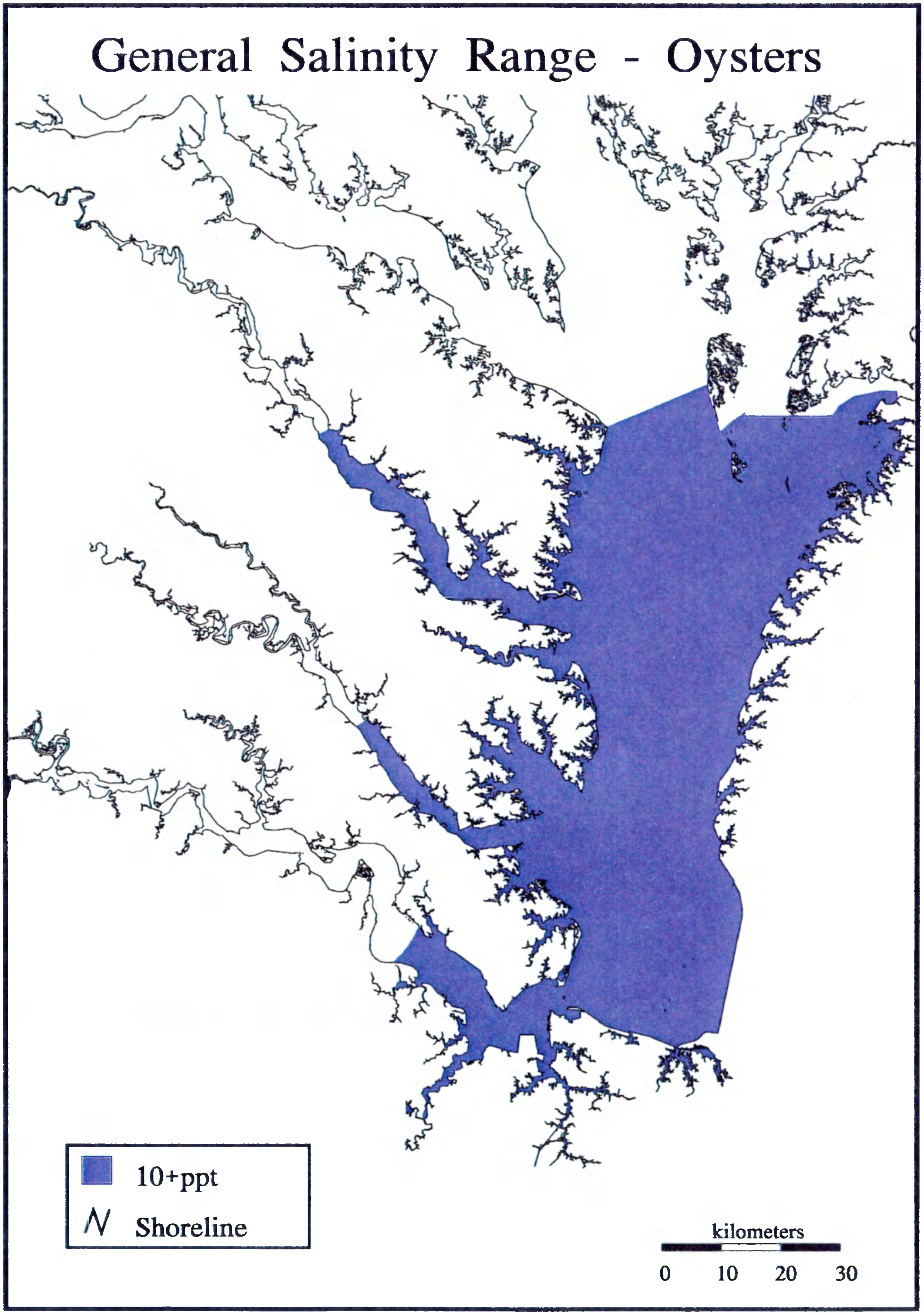

General Salinity Range - Oysters
10+ppt
Shoreline
kilometers
0
10
20
30

Fig. 10

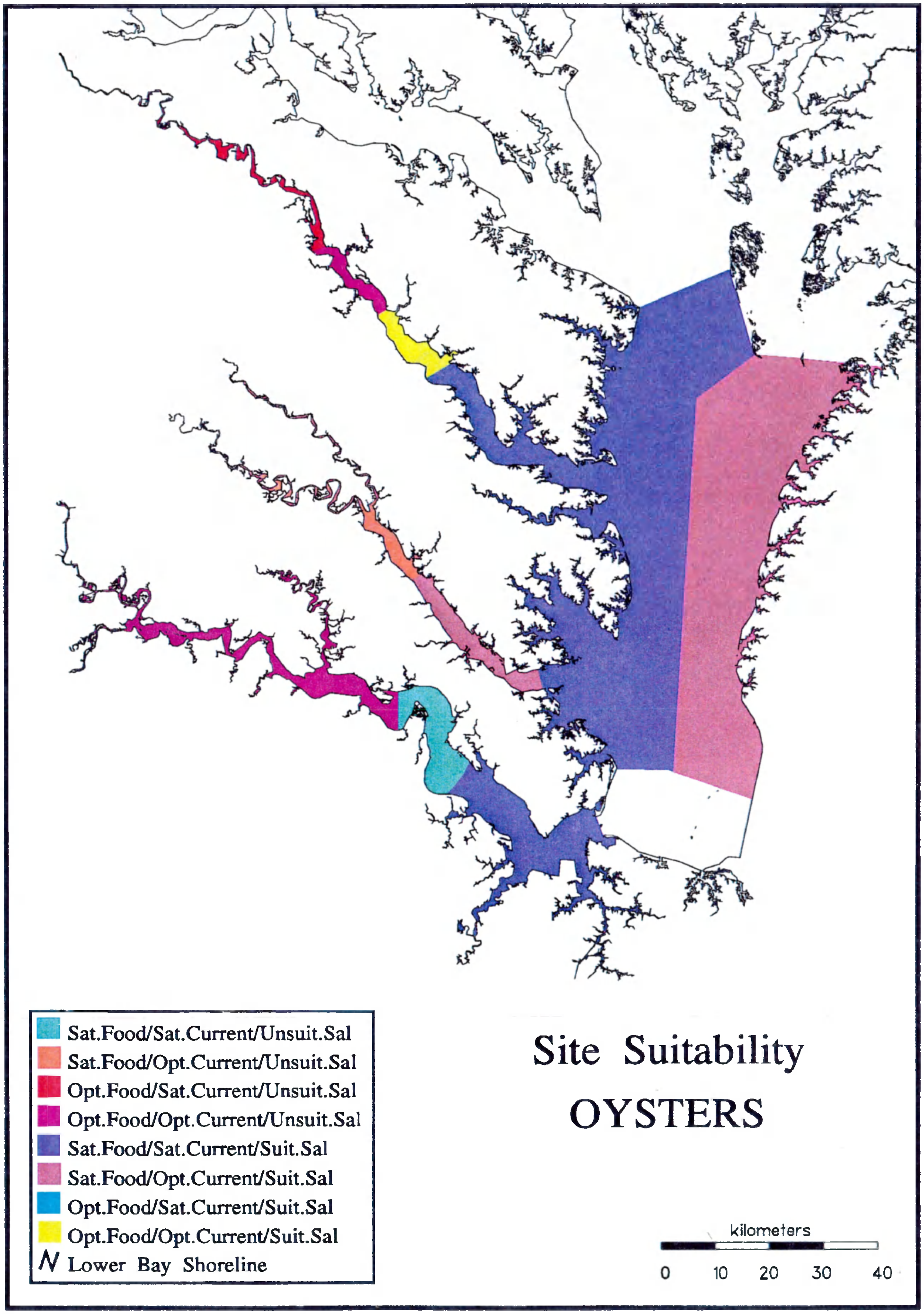
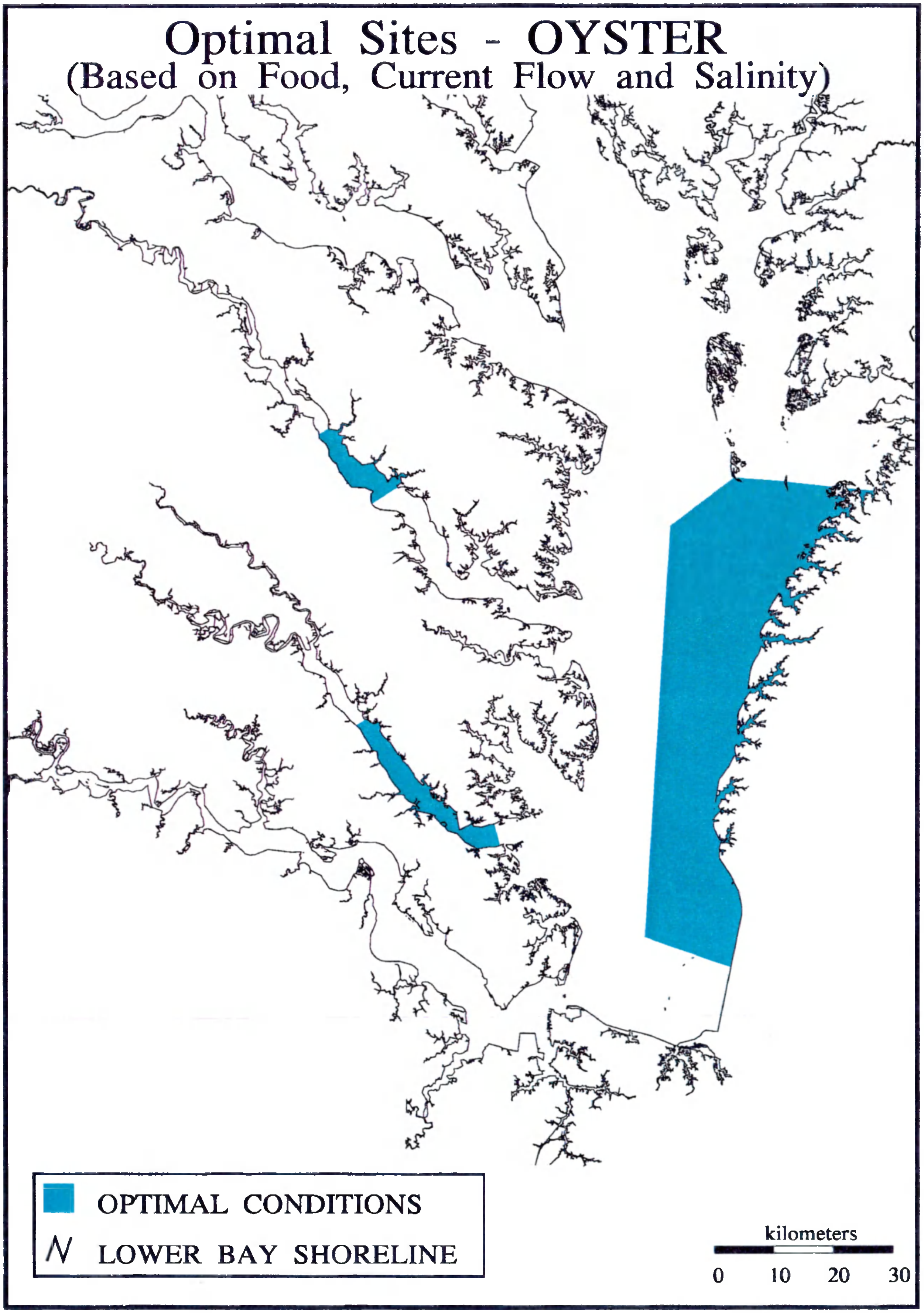

Sat.Food/Sat.Current/Unsuit.Sal
Sat.Food/Opt.Current/Unsuit.Sal
Opt.Food/Sat.Current/Unsuit.Sal
Opt.Food/Opt.Current/Unsuit.Sal
Sat.Food/Sat.Current/Suit.Sal
Sat.Food/Opt.Current/Suit.Sal
Opt.Food/Sat.Current/Suit.Sal
Opt.Food/Opt.Current/Suit.Sal
Lower Bay Shoreline
Site Suitability
OYSTERS
kilometers
0
10
20
30
40

Fig. 11



Optimal Sites - OYSTER
(Based on Food, Current Flow and Salinity)
OPTIMAL CONDITIONS
LOWER BAY SHORELINE
kilometers
0
10
20
30

Fig. 12

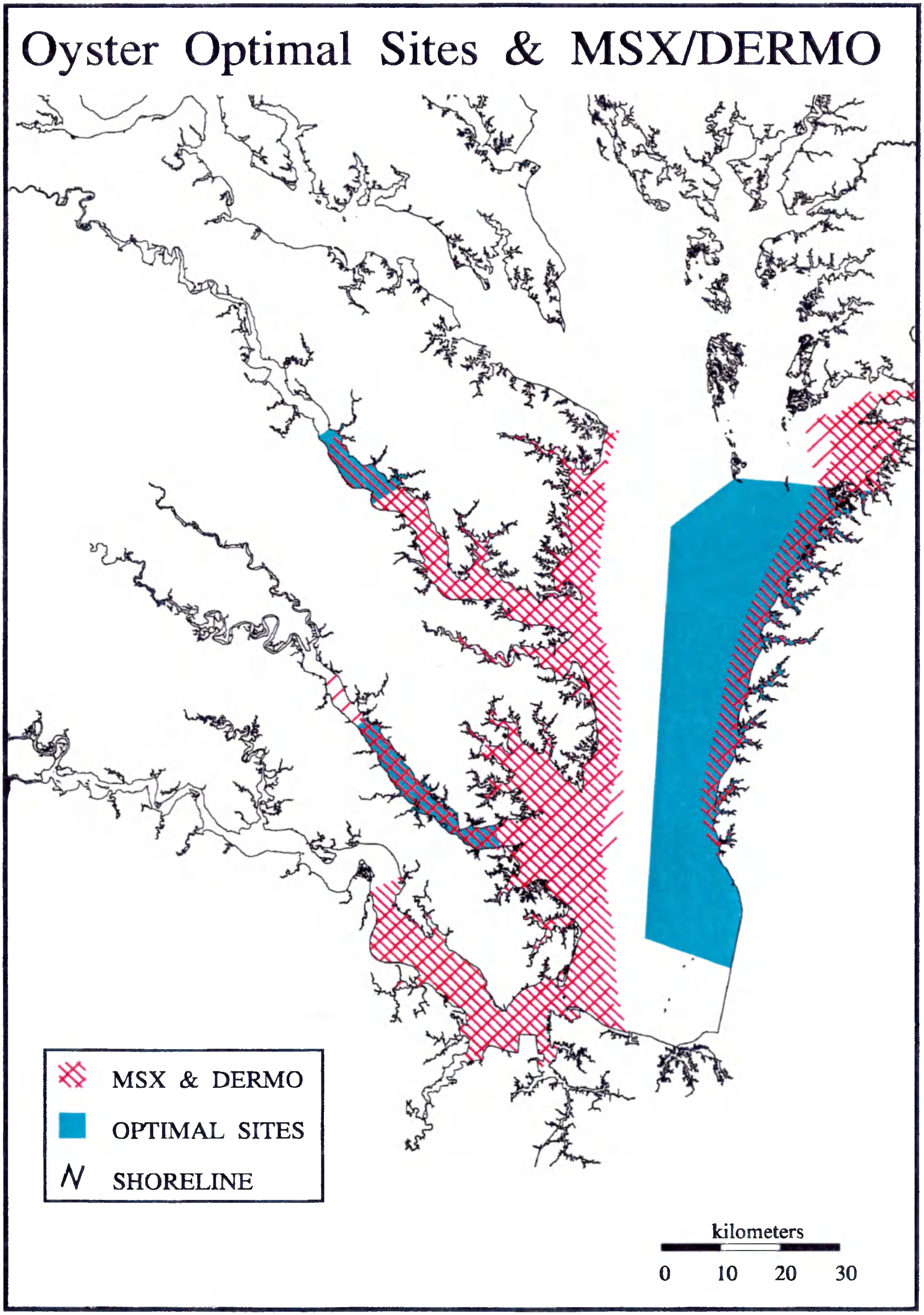
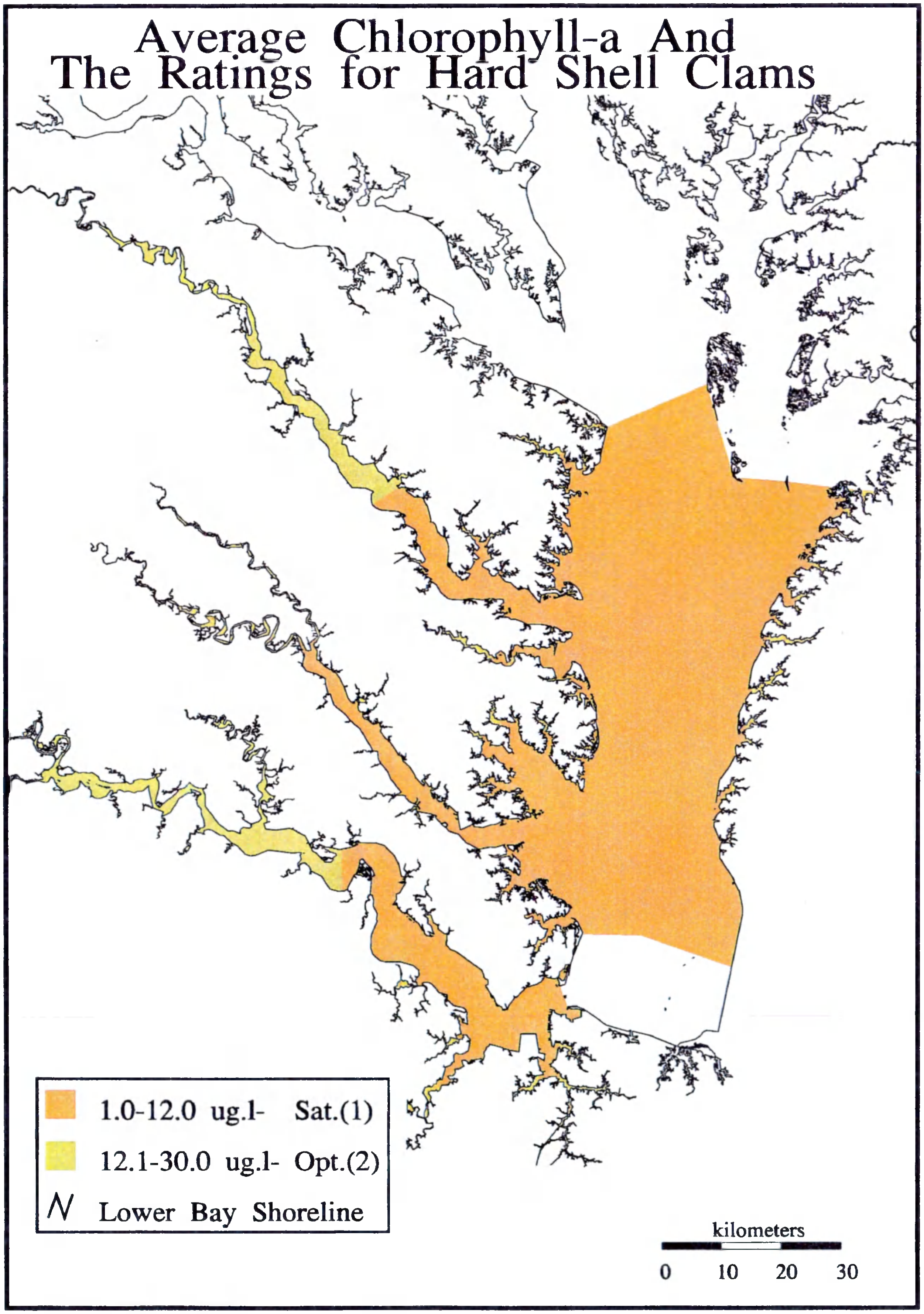

Oyster Optimal Sites & MSX/DERMO
MSX & DERMO
OPTIMAL SITES
SHORELINE
kilometers
0
10
20
30

Fig. 13



Average Chlorophyll-a And
The Ratings for Hard Shell Clams
1.0-12.0 ug.l- Sat.(1)
12.1-30.0 ug.l- Opt.(2)
Lower Bay Shoreline
kilometers
0 10 20 30

Fig. 14

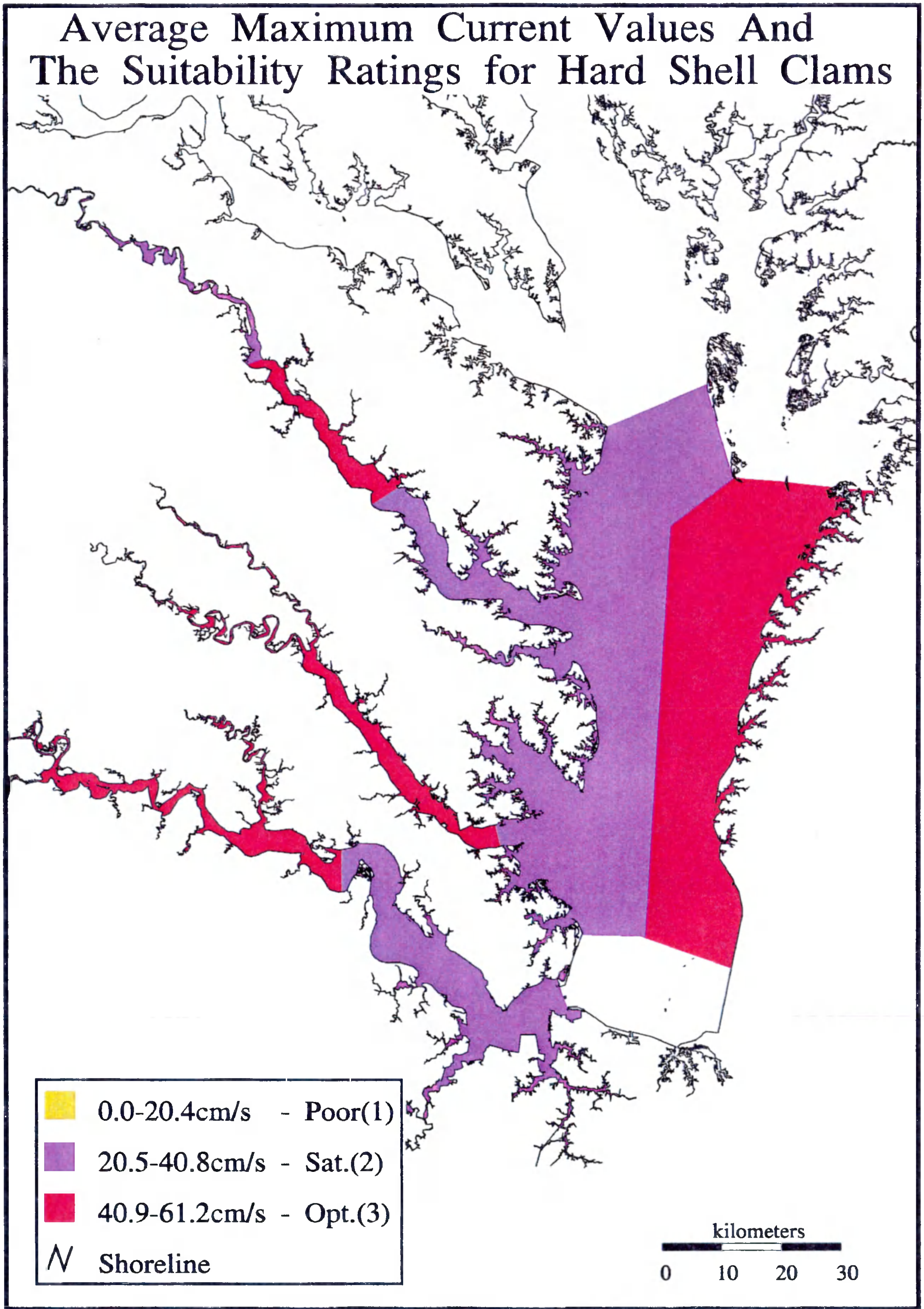

Average Maximum Current Values And
The Suitability Ratings for Hard Shell Clams
0.0-20.4cm/s - Poor(1)
20.5-40.8cm/s - Sat.(2)
40.9-61.2cm/s - Opt.(3)
Shoreline
kilometers
0 10 20 30

Fig. 15

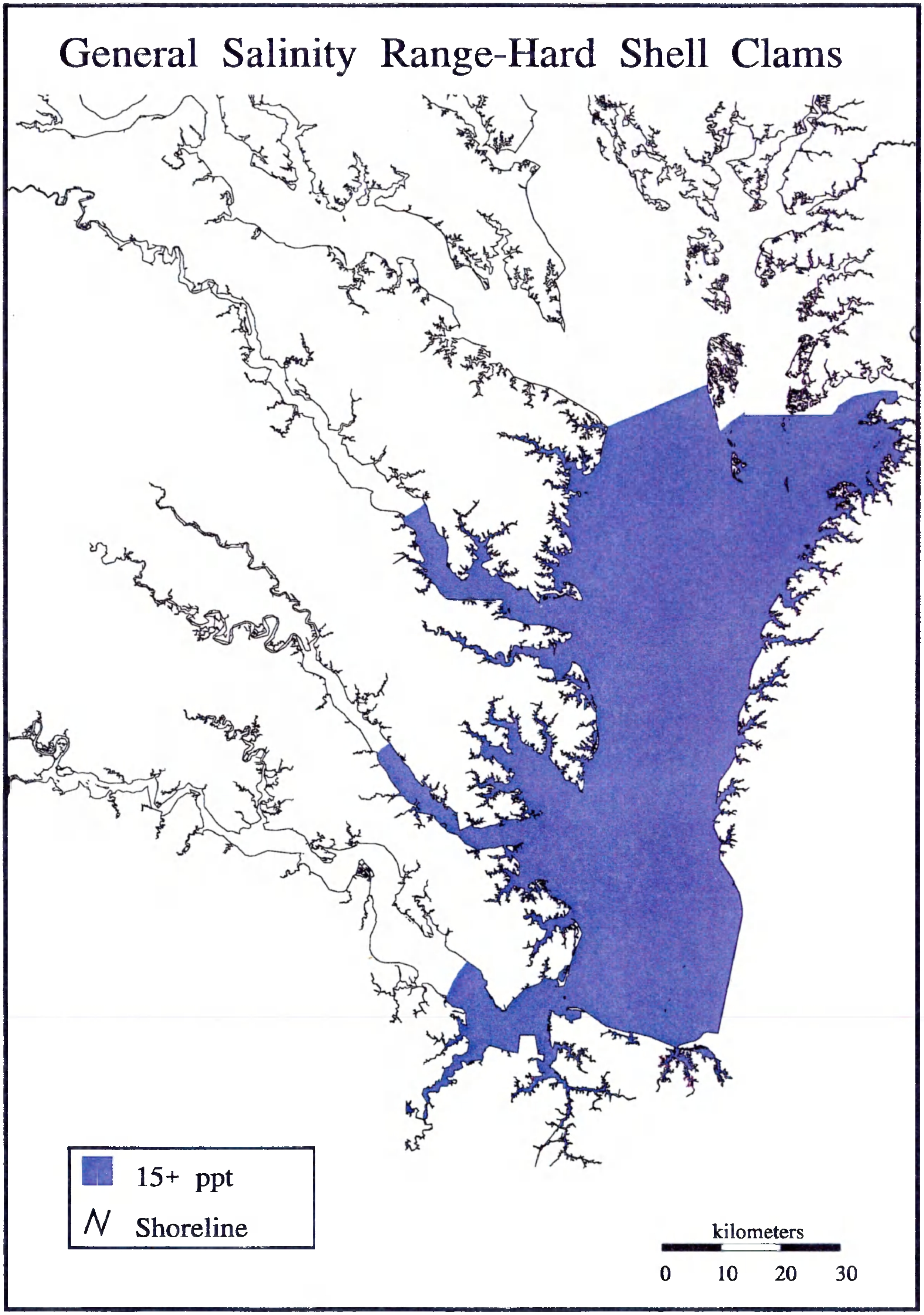

General Salinity Range-Hard Shell Clams
15+ ppt
Shoreline
kilometers
0
10
20
30

Fig. 16

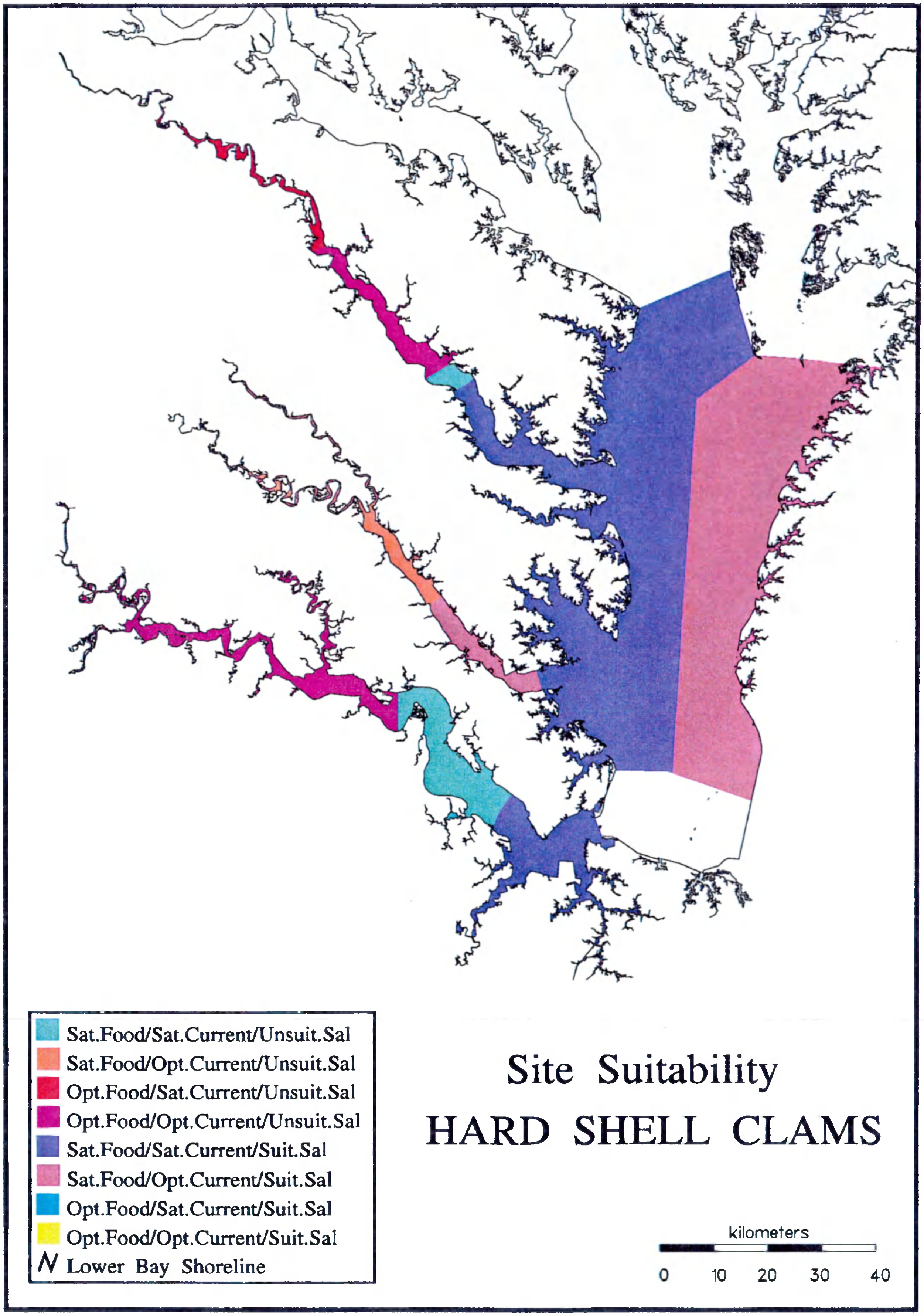

Sat.Food/Sat.Current/Unsuit.Sal
Sat.Food/Opt.Current/Unsuit.Sal
Opt.Food/Sat.Current/Unsuit.Sal
Opt.Food/Opt.Current/Unsuit.Sal
Sat.Food/Sat.Current/Suit.Sal
Sat.Food/Opt.Current/Suit.Sal
Opt.Food/Sat.Current/Suit.Sal
Opt.Food/Opt.Current/Suit.Sal
N Lower Bay Shoreline
Site Suitability
HARD SHELL CLAMS
kilometers
0 10 20 30 40

Fig. 17

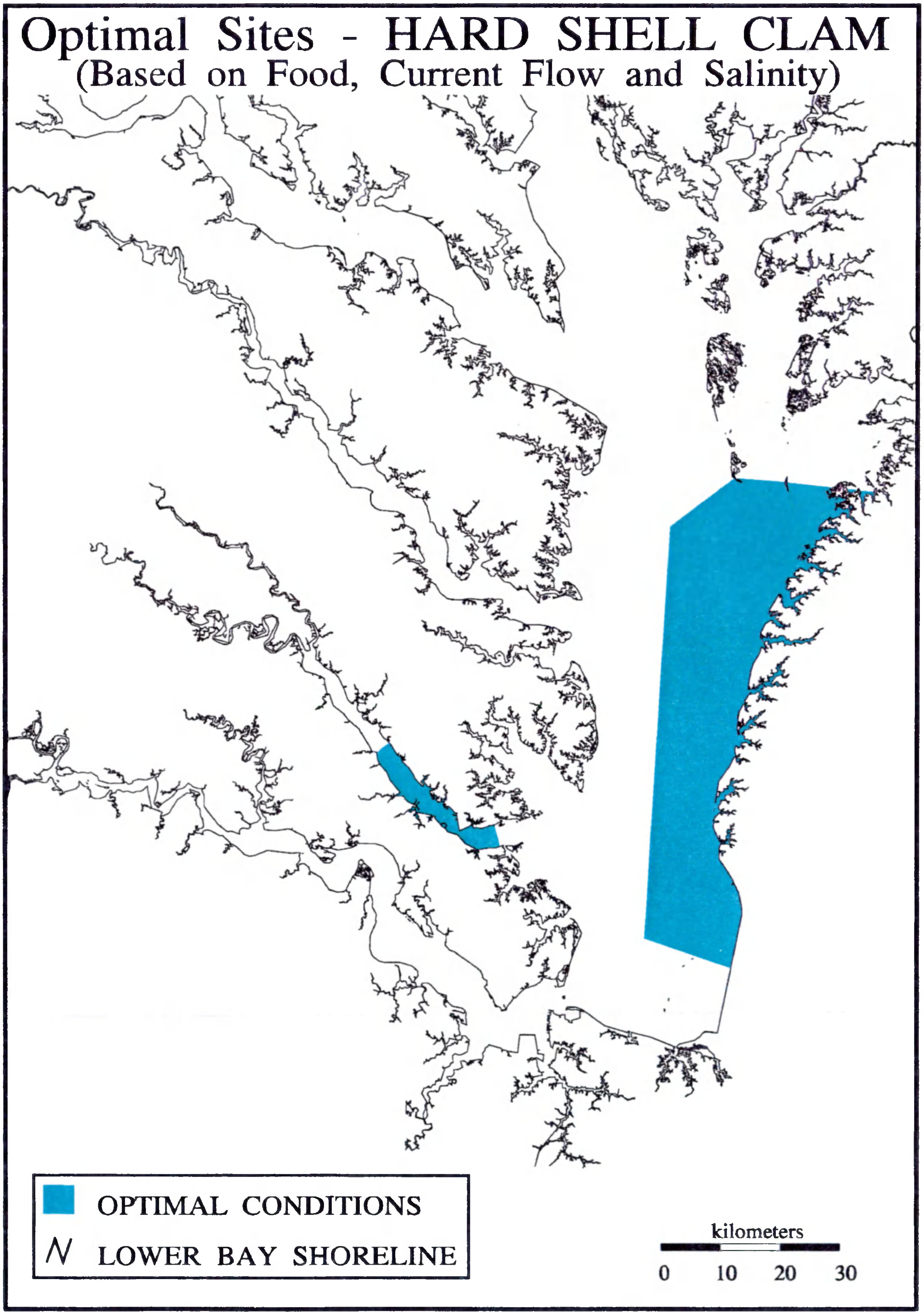

Optimal Sites - HARD SHELL CLAM
(Based on Food, Current Flow and Salinity)
OPTIMAL CONDITIONS
LOWER BAY SHORELINE
kilometers
0
10
20
30

Fig. 18

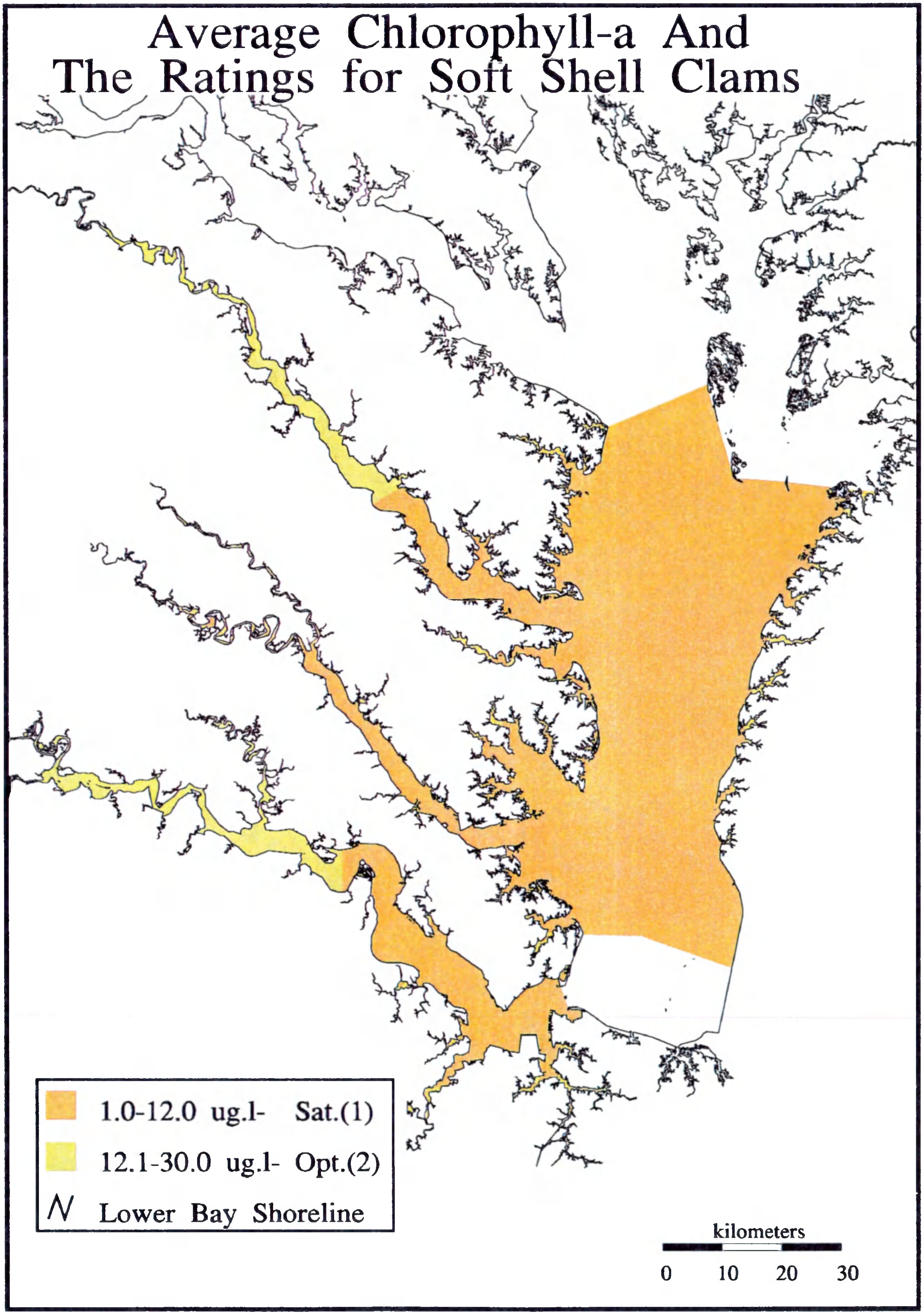

Average Chlorophyll-a And
The Ratings for Soft Shell Clams
1.0-12.0 ug.l- Sat.(1)
12.1-30.0 ug.l- Opt.(2)
Lower Bay Shoreline
kilometers
0 10 20 30

Fig. 19

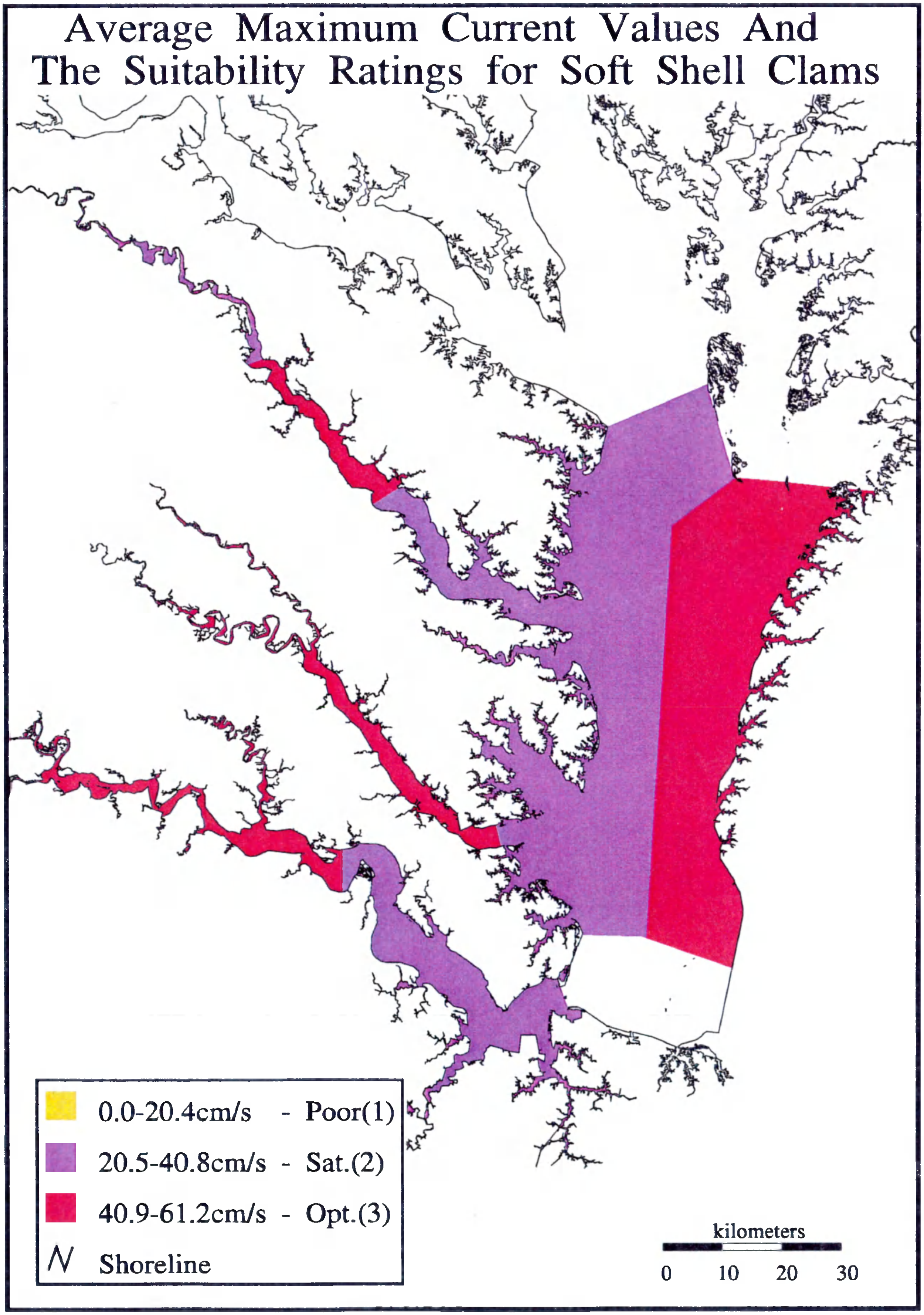

Average Maximum Current Values And
The Suitability Ratings for Soft Shell Clams
0.0-20.4cm/s - Poor(1)
20.5-40.8cm/s - Sat.(2)
40.9-61.2cm/s - Opt.(3)
Shoreline
kilometers
0 10 20 30

Fig. 20

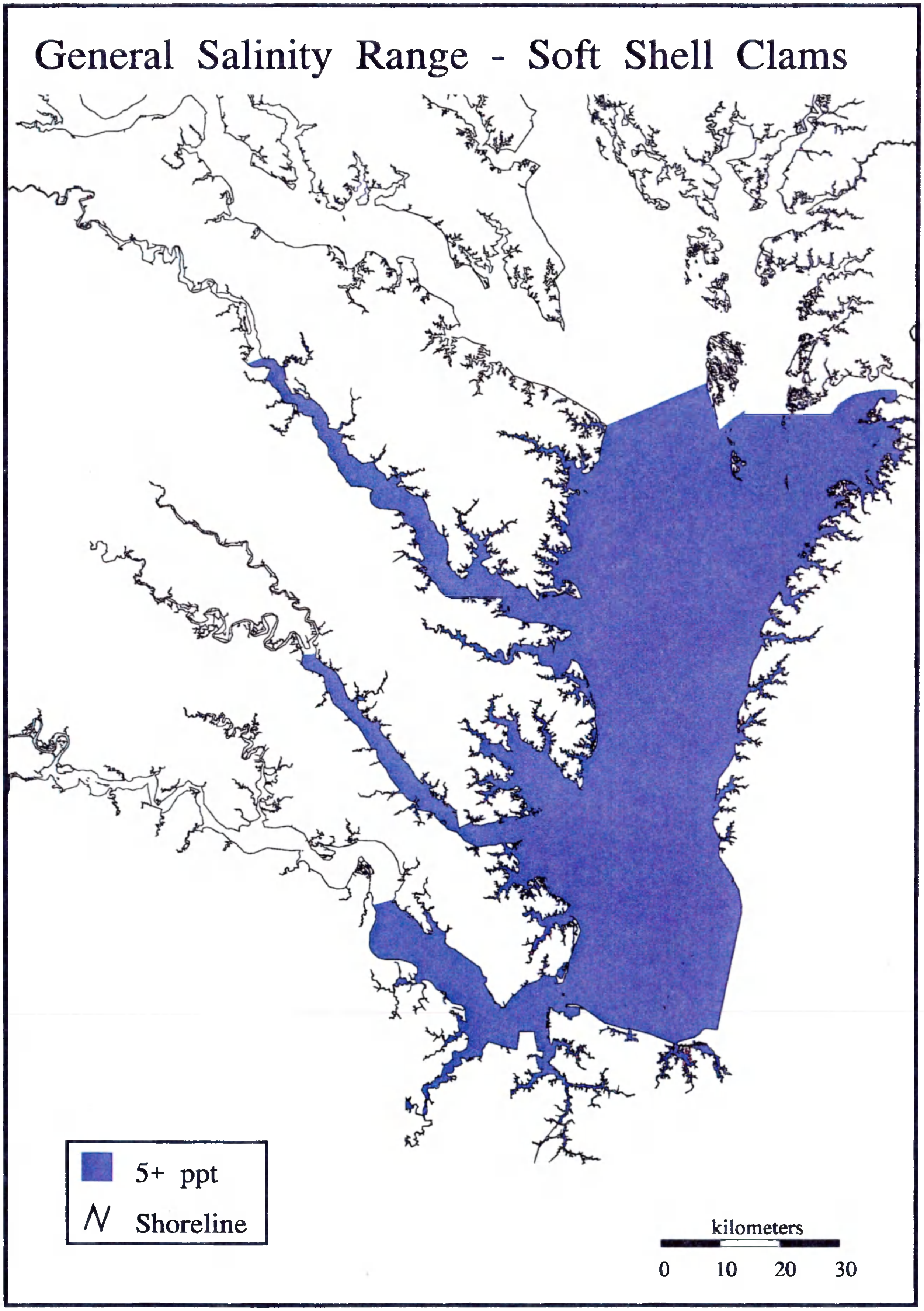

General Salinity Range - Soft Shell Clams
5+ ppt
Shoreline
kilometers
0
10
20
30

Fig. 21

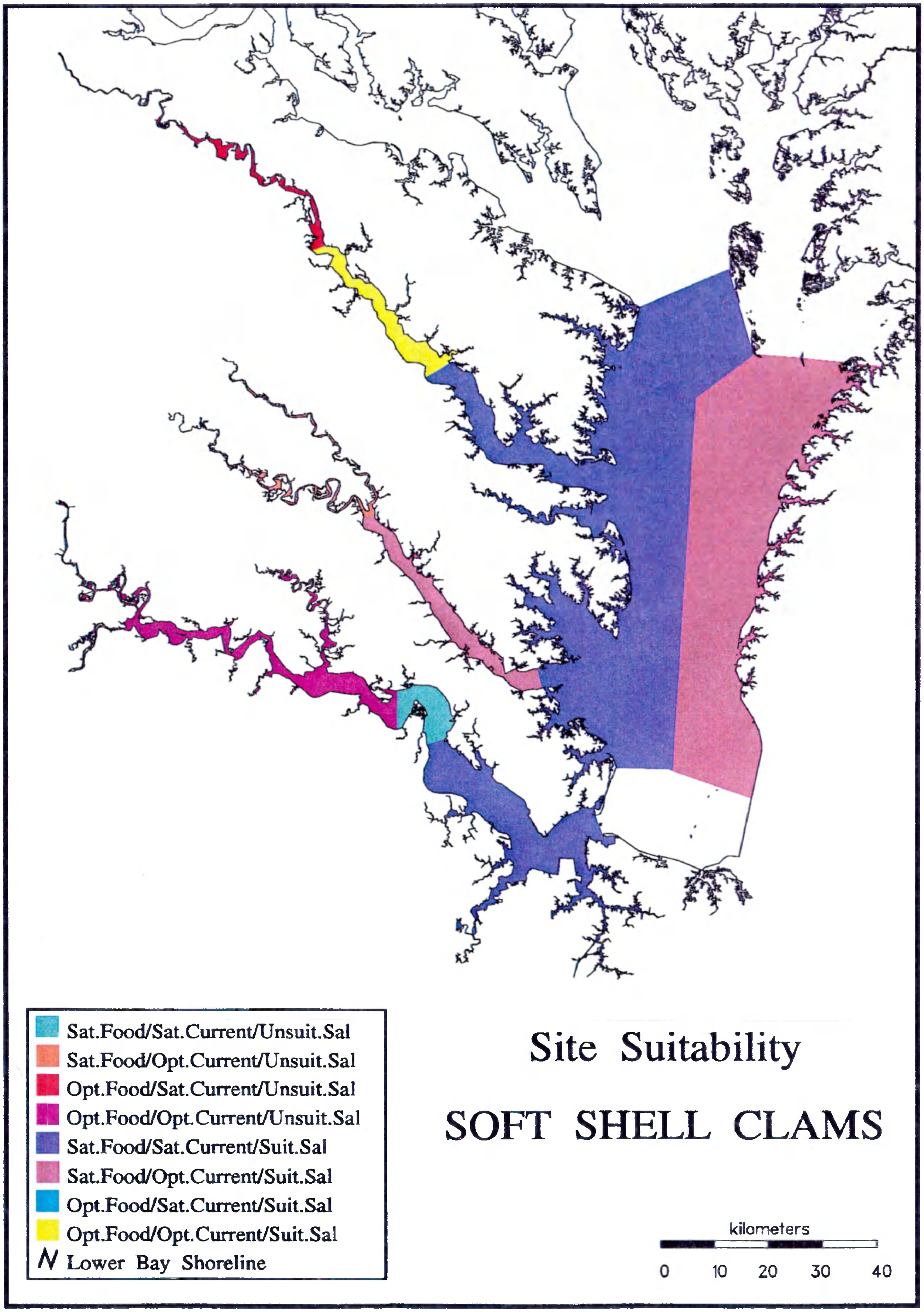

Sat.Food/Sat.Current/Unsuit.Sal
Sat.Food/Opt.Current/Unsuit.Sal
Opt.Food/Sat.Current/Unsuit.Sal
Opt.Food/Opt.Current/Unsuit.Sal
Sat.Food/Sat.Current/Suit.Sal
Sat.Food/Opt.Current/Suit.Sal
Opt.Food/Sat.Current/Suit.Sal
Opt.Food/Opt.Current/Suit.Sal
Lower Bay Shoreline
Site Suitability
SOFT SHELL CLAMS
kilometers
0
10
20
30
40

Fig. 22

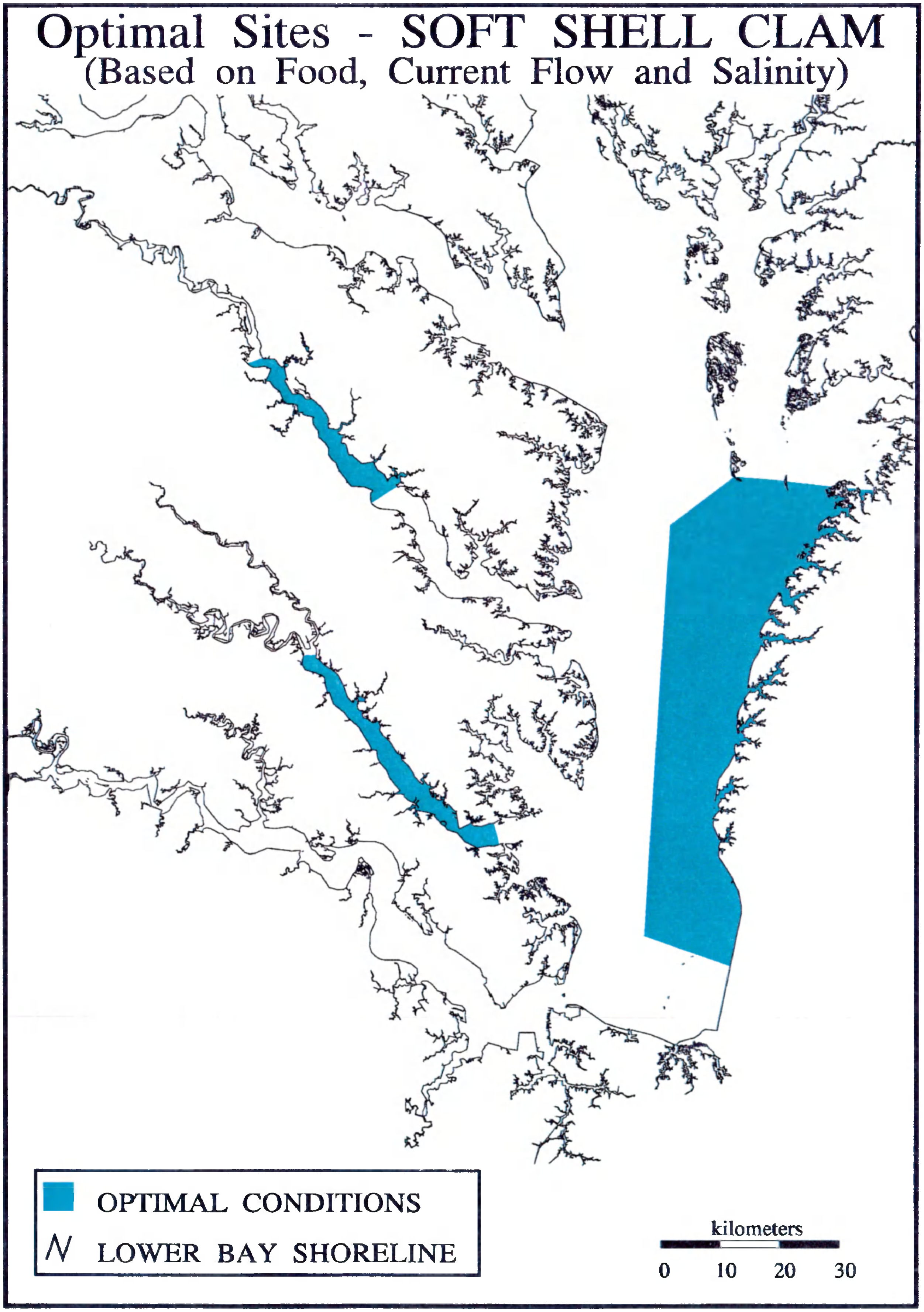

Optimal Sites - SOFT SHELL CLAM
(Based on Food, Current Flow and Salinity)
OPTIMAL CONDITIONS
LOWER BAY SHORELINE
kilometers
0 10 20 30

Fig. 23

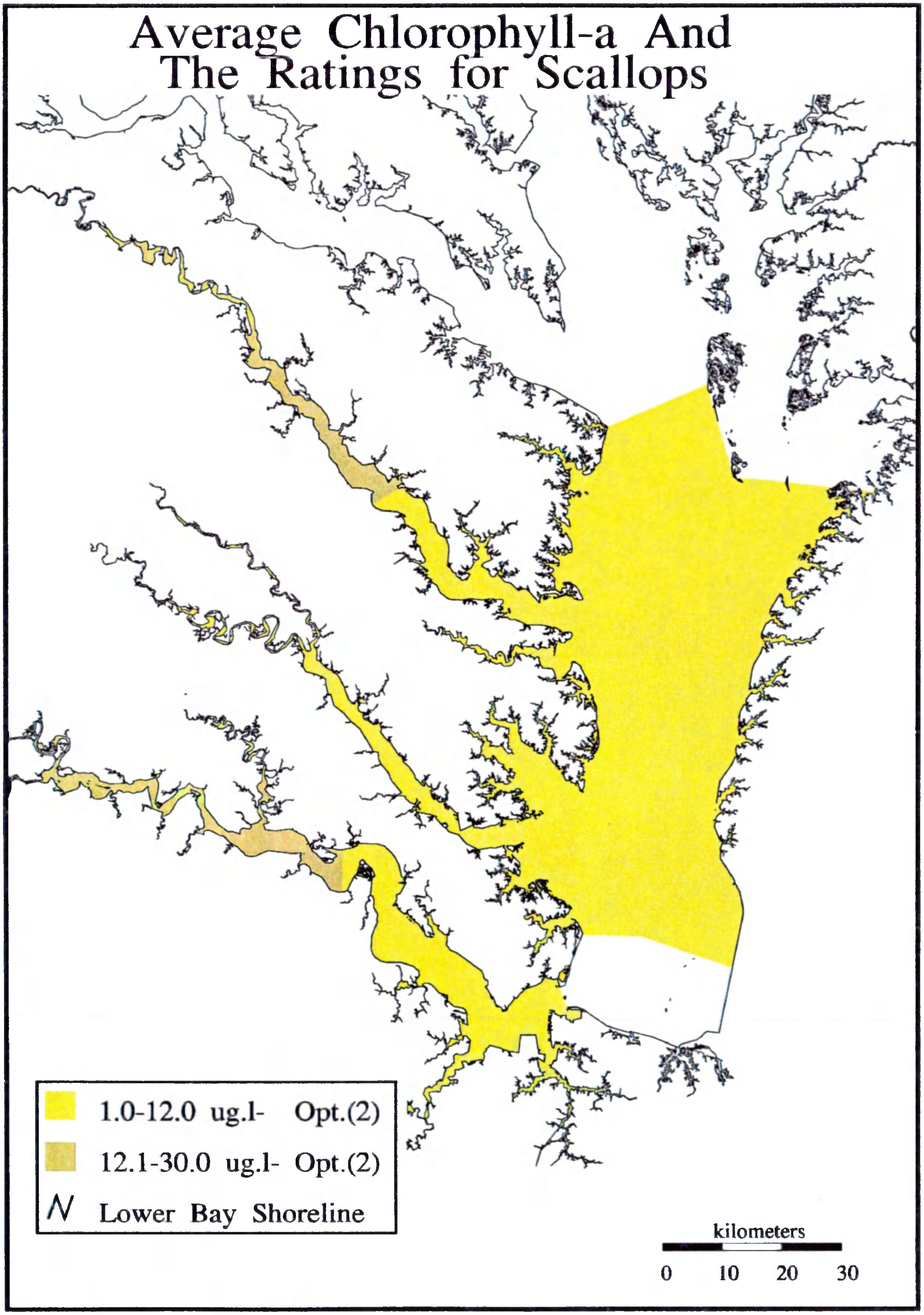

Average Chlorophyll-a And
The Ratings for Scallops
1.0-12.0 ug.l- Opt.(2)
12.1-30.0 ug.l- Opt.(2)
Lower Bay Shoreline
kilometers
0 10 20 30

Fig. 24

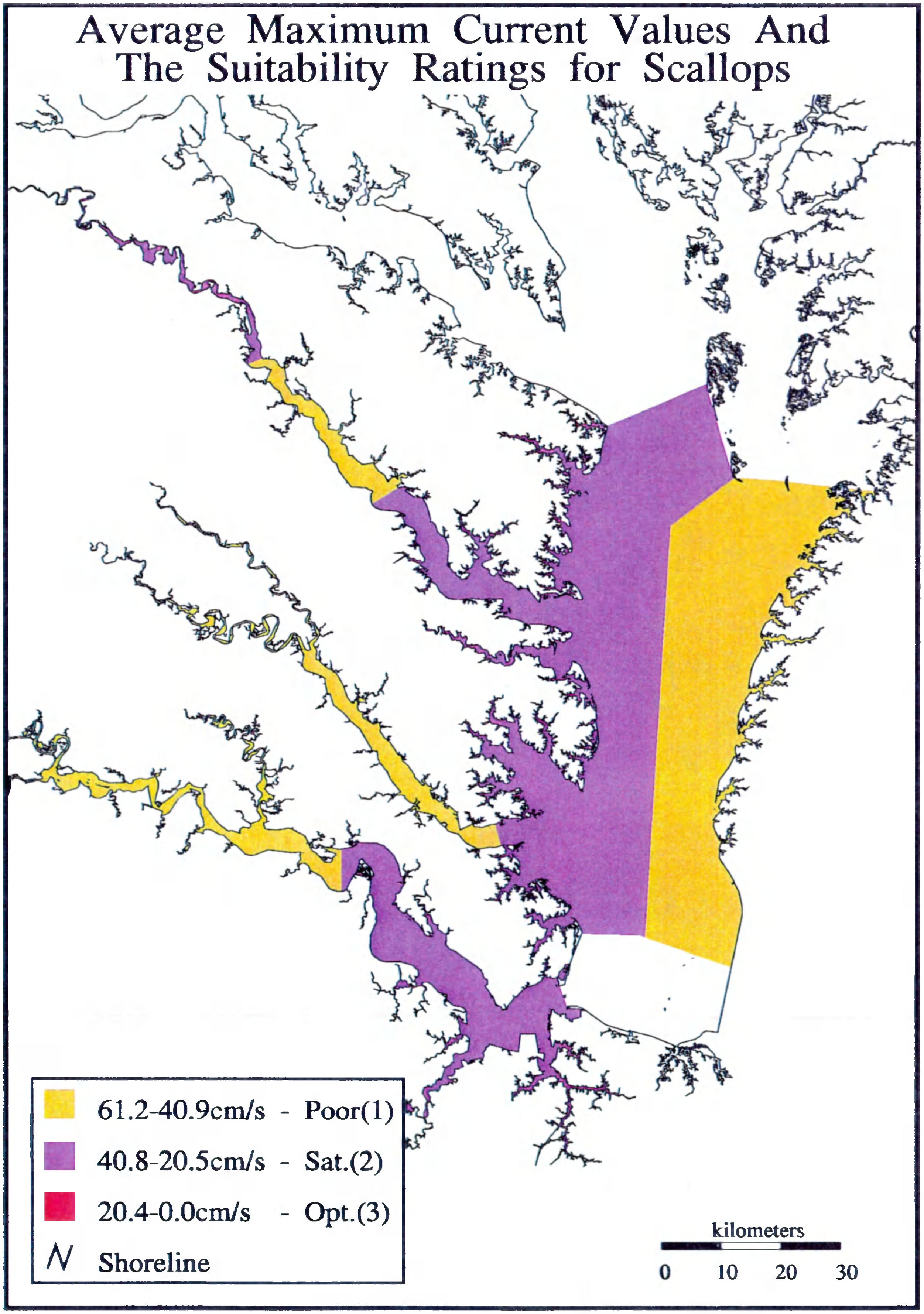

Average Maximum Current Values And
The Suitability Ratings for Scallops
61.2-40.9cm/s - Poor(1)
40.8-20.5cm/s - Sat.(2)
20.4-0.0cm/s - Opt.(3)
Shoreline
kilometers
0
10
20
30

Fig. 25

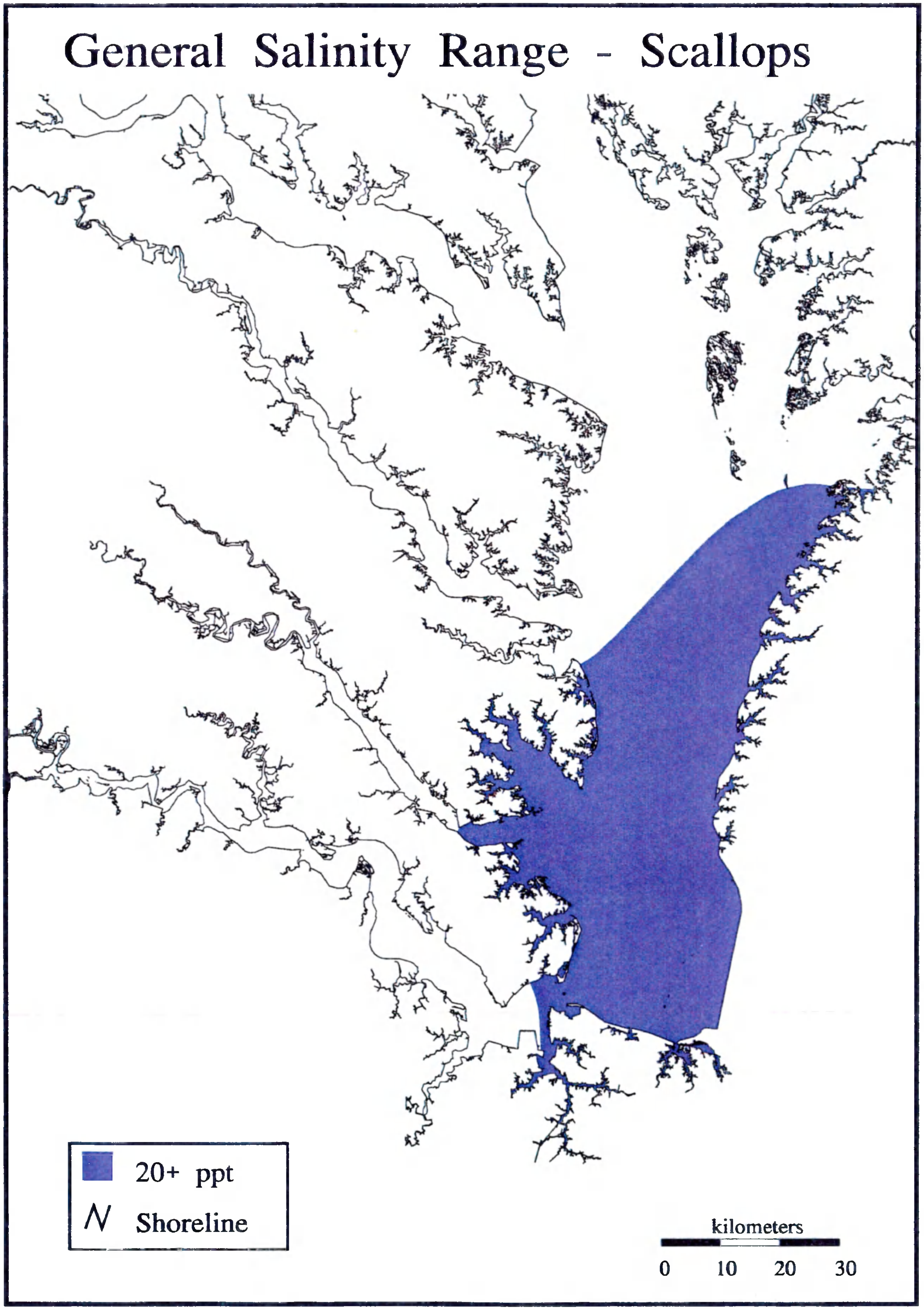
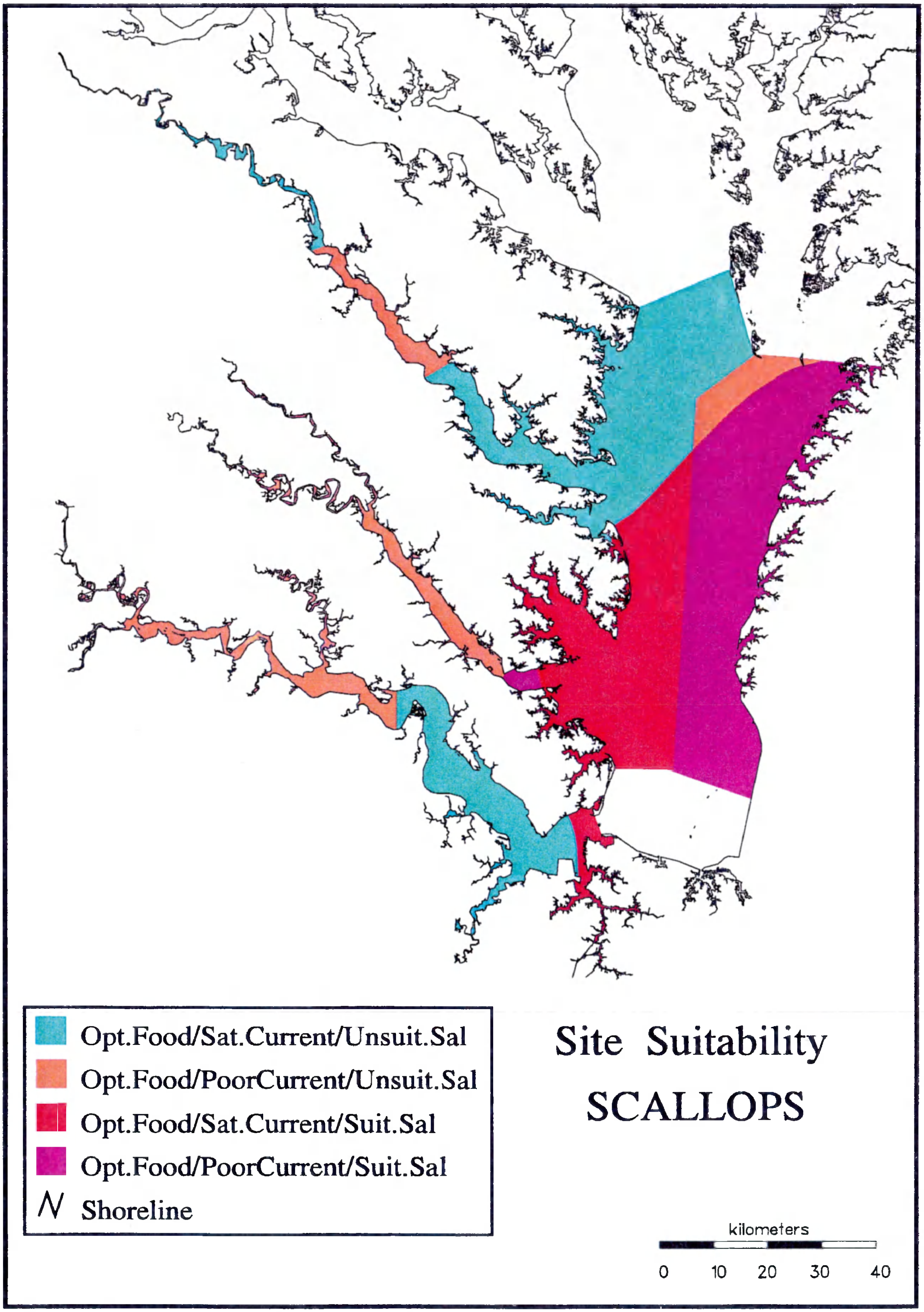

General Salinity Range - Scallops
20+ ppt
Shoreline
kilometers
0 10 20 30

Fig. 26



Opt.Food/Sat.Current/Unsuit.Sal
Opt.Food/PoorCurrent/Unsuit.Sal
Opt.Food/Sat.Current/Suit.Sal
Opt.Food/PoorCurrent/Suit.Sal
Shoreline
Site Suitability
SCALLOPS
kilometers
0
10
20
30
40

Fig. 27

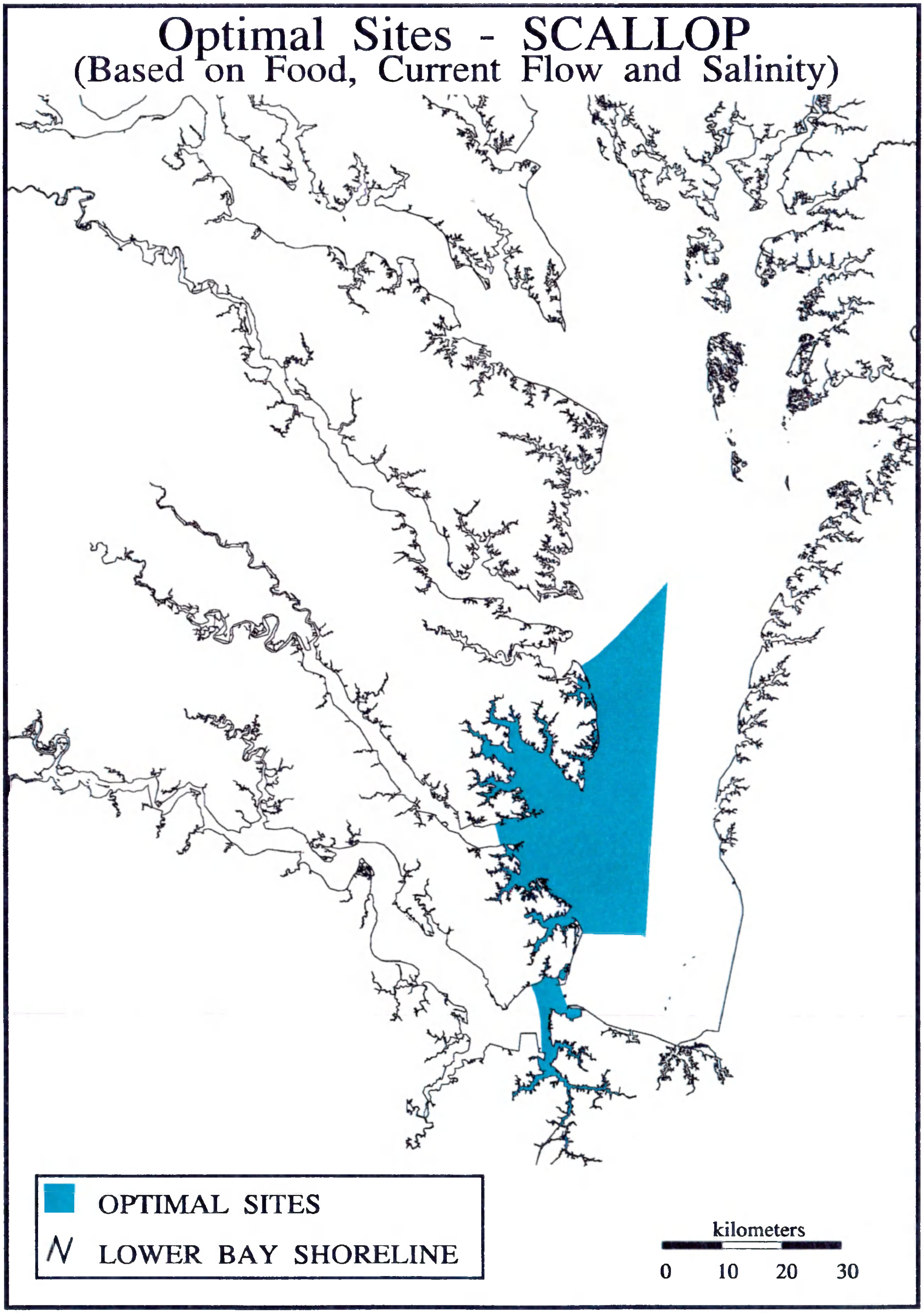
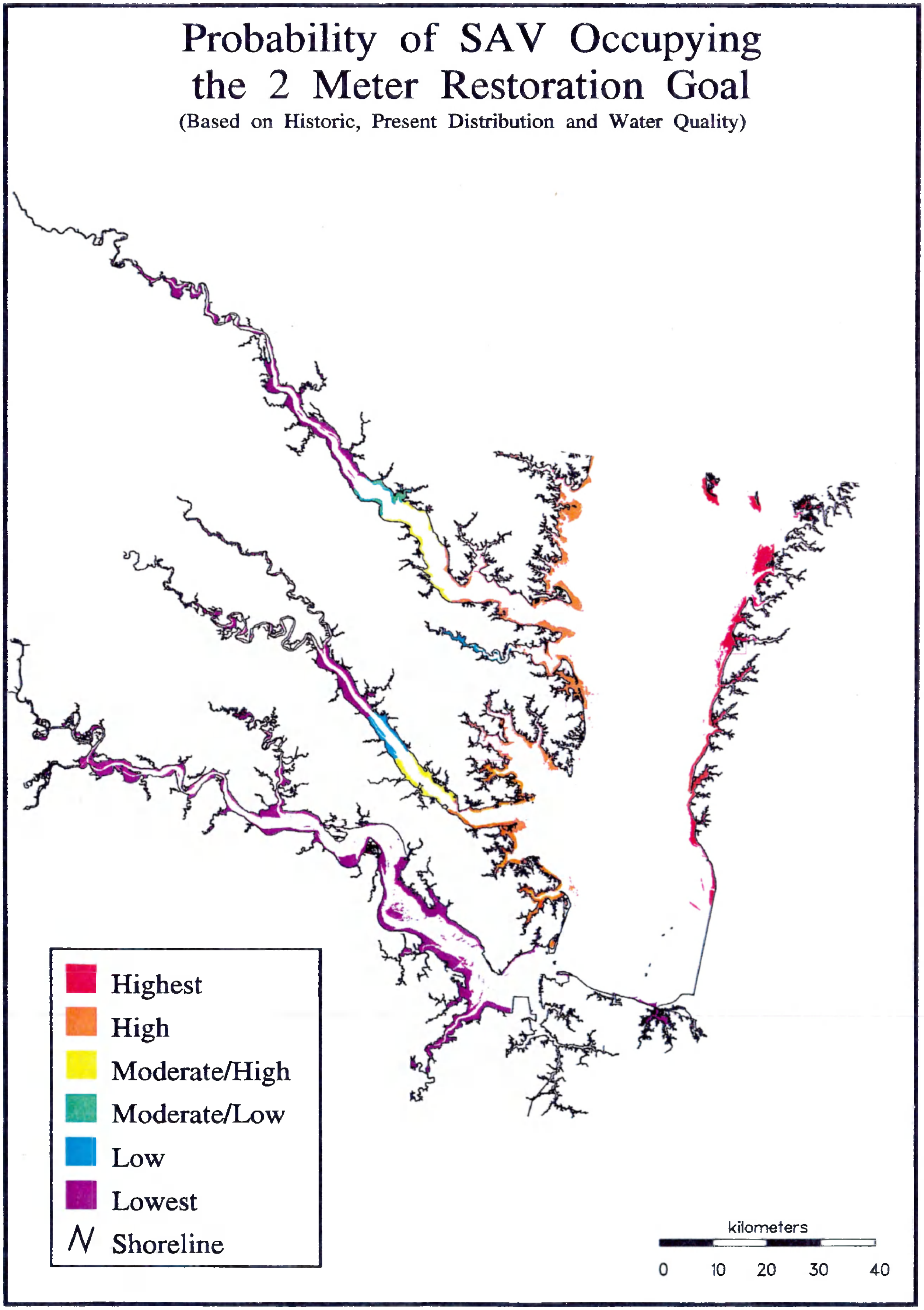

Optimal Sites - SCALLOP
(Based on Food, Current Flow and Salinity)
OPTIMAL SITES
LOWER BAY SHORELINE
kilometers
0
10
20
30

Fig. 28



Probability of SAV Occupying
the 2 Meter Restoration Goal
(Based on Historic, Present Distribution and Water Quality)
Highest
High
Moderate/High
Moderate/Low
Low
Lowest
Shoreline
kilometers
0
10
20
30
40

Fig. 29

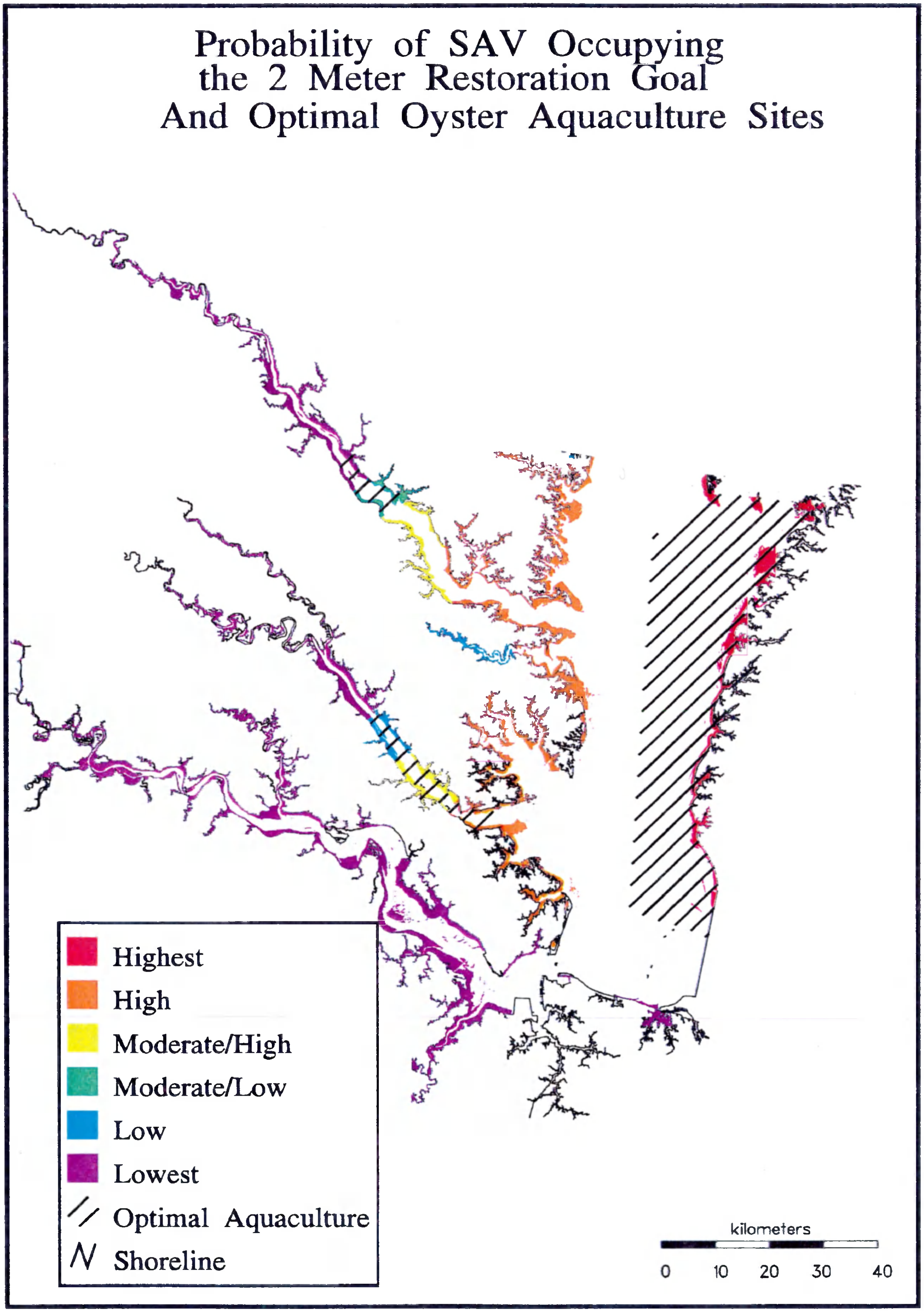

Probability of SAV Occupying
the 2 Meter Restoration Goal
And Optimal Oyster Aquaculture Sites
Highest
High
Moderate/High
Moderate/Low
Low
Lowest
Optimal Aquaculture
Shoreline
kilometers
0
10
20
30
40

Fig. 30

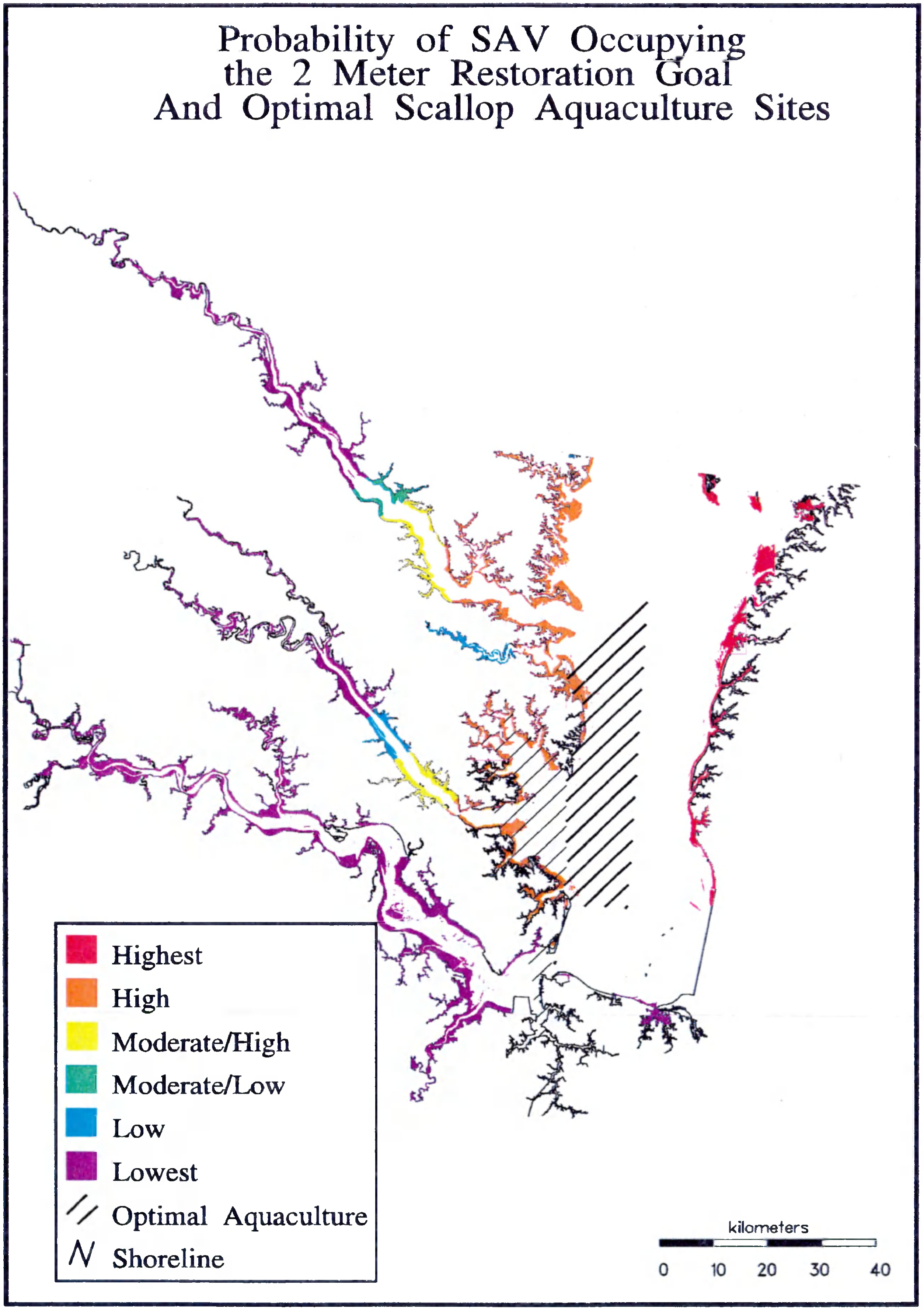
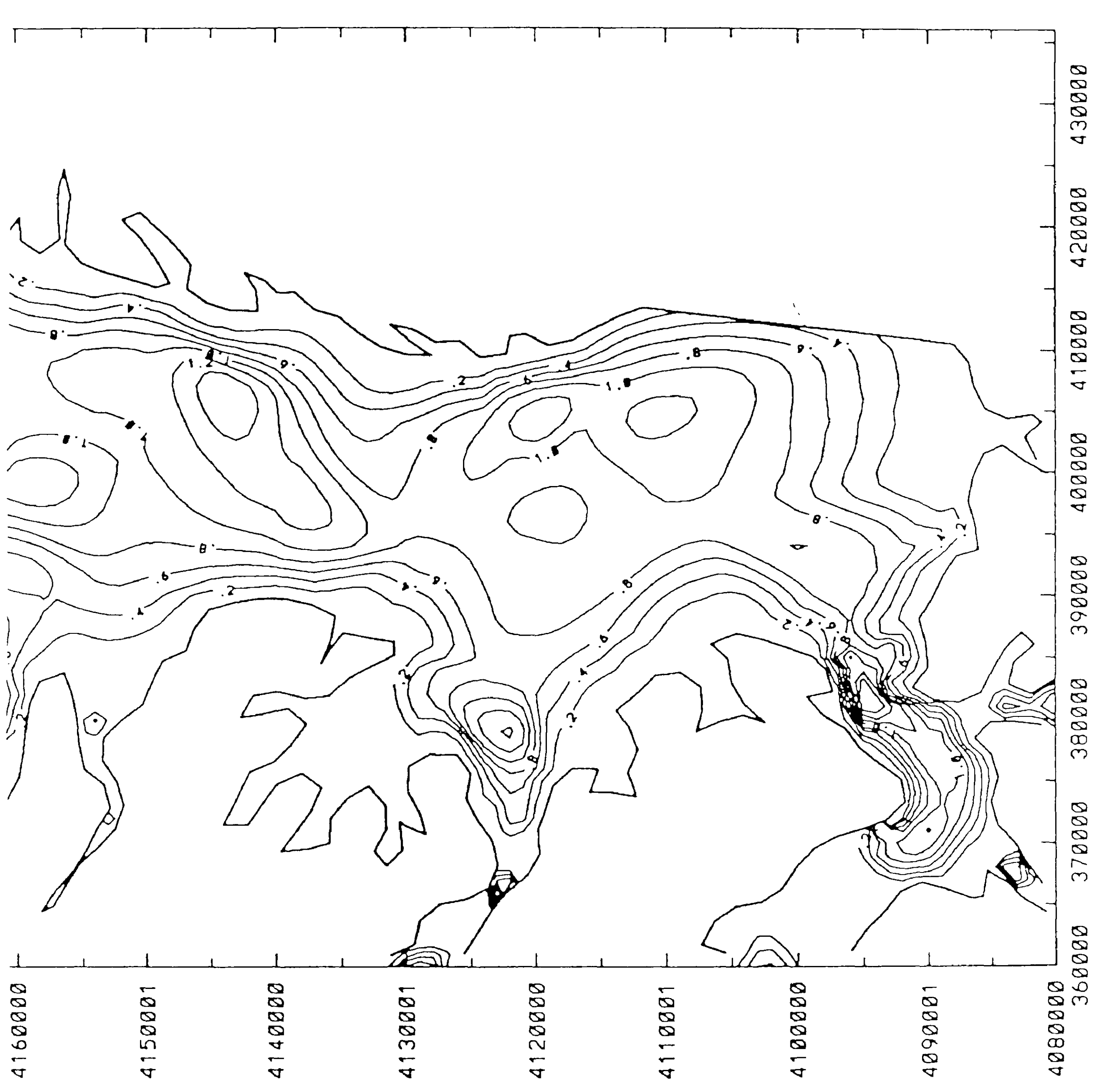

Probability of SAV Occupying
the 2 Meter Restoration Goal
And Optimal Scallop Aquaculture Sites
Highest
High
Moderate/High
Moderate/Low
Low
Lowest
Optimal Aquaculture
Shoreline
kilometers
0 10 20 30 40

Fig. 31



ax Tidal Vel.

Fig. 32

TABLES

LIST OF TABLES

LIST OF TABLES (Continued)

Table 1. Chesapeake Bay SAV Habitat Requirements.

	SAV Habitat Requirements For One Meter Restoration — Habitat Requirements Which Effect Water Column/Leaf Surface Light Attenuation						SAV Habitat Requirements For Two Meter Restoration	
Salinity Regime	Light Attenuation Coefficient (m-)	Total Suspended Solids (mg/l)	Chlorophyll *a* (µg/l)	Dissolved Inorganic Nitrogen (mg/l)	Dissolved Inorganic Phosphorus (mg/l)	Critical Life Period	Light Attenuation Coefficient (m-)	Critical Life Period
Tidal Fresh	<2	<15	<15	—	<0.02	April-October	<0.8	April-October
Oligohaline	<2	<15	<15	—	<0.02	April-October	<0.8	April-October
Mesohaline	<1.5	<15	<15	<0.15	<0.01	April-October	<0.8	April-October
Polyhaline	<1.5	<15	<15	<0.15	<0.02	March-November	<0.8	March-November

Table 2. Principal Requirements for Shellfish Aquaculture - Values Based on Literature Cited Below.

Organism	Salinity Range	Available Food	Current Flow
Oyster	10-35 ppt +(Hopkins 1936; Quayle 1969) +(King 1977; Bernard 1983)	1-55 ug/L chl-a 12+ ug/L chl-a -Opt. +(Tenore & Dunstan 1973) +(Malouf & Breese 1977) +(Bernard 1983)	Optimal- Strong tidal flow avoiding heavy wave action or stagnant water +(Westley 1965; Walne 1972; Frechette & Bourget 1985)
Hard Shell Clam	15-35 ppt ▮(Hamwi 1967)	2 x 10^5 cells/ml ✧(Tenore & Dunstan 1973)	Growth positively coorelated with flow rate in the cultured system ✧(Walne 1972) Exposed habitats containing considerable tidal currents (77.16-128.6 cm/s) are optimal ▲(Fraser & Smith 1928) ▲(Goodwin 1971, 1973) ▲(Paul & Feder 1973) ▲(Peterson 1977)
Soft Shell Clam	5+ ppt ○(Schubel 1973) ✧(Chanley & Andrews 1971)	Grow best where food is relatively abundant ○(Belding 1930) ○(Newell 1982)	Faster currents cause faster growth ○(Appleldoorn 1982)
Bay Scallop	20+ ppt (Oesterling 1993 per comm.)	1.2 ug/L min. less can cause stunting but more does not affect growth ❑(Rhodes 1981) ❑Kirby & Smith & Barber 1974)	Growth inversely proportional to flow rate ❑(Kirby & Smith 1972)

▲ Rodnick & Li 1983
+ Brown & Hartwick 1988
✧ Funderburk et al. 1991
○ Newell & Hidu 1982
❑ Brotman 1992
▮ Manzi & Castagna 1986

Table 3. Scoring System of Two Biophysical Parameters Necessary for the Successful Culture of Oysters, Hard Shell Clams and Soft Shell Clams.

Biophysical Parameter	Numerical Value	Suitability	Score
Chlorophyll-a (ug/L)	1.0 - 12.0	Satisfactory	1
	12.1 - 30.0	Optimal	2
Current Velocity (cm/s)	0.1 - 20.4	Poor	1
	20.5 - 40.8	Satisfactory	2
	40.9 - 61.2	Optimal	3

NOTE:Values and scores were based on Table 2 references

Table 4. Scoring System of Two Biophysical Parameters Necessary for the Successful Culture of Bay Scallops

Biophysical Parameter	Numerical Value	Suitability	Score
Chlorophyll-a (ug/L)	1.0 - 12.0	Optimal	2
	12.1 - 30.0	Optimal	2
Current Velocity (cm/s)	0.1 -20.4	Optimal	3
	20.5 - 40.8	Satisfactory	2
	40.9 - 61.2	Poor	1

NOTE: Values and scores were based on Table 2 references

Table 5. Average Chlorophyll-a per Segment and Appropriate Score

Segment No.	Avg. Chlorphyll-a	Score (O,HC,SC)*	Score (SCA)*
CB-7	4.5	1	2
CB-6	6.0	1	2
CB-8	NO DATA	-	-
LE-5	6.6	1	2
RET-5	20.3	2	2
TF-5	13.0	2	2
WE-4	6.8	1	2
LE-4	8.8	1	2
RET-4	10.1	1	2
TF-4	1.3	1	2
LE-3	8.8	1	2
RET-3	16.0	2	2
TF-3	13.0	2	2
CB-5	7.4	1	2

*(O,HC,SC) = Oysters, Hard Shell Clams and Soft Shell Clams
*(SCA) = Scallops

NOTE: The chlorophyll-a values used to calculate the above averages were obtained from the 1989 Chesapeake Bay Monitoring Program water quality data.

Table 6. Average Maximum Flood Velocity per Segment and Appropriate Score

Segment No.	Avg. Max. Flood (cm/s)	Score (O,HC,SC)*	Score (SCA)*
CB-7	45.9	3	1
CB-6	35.7	2	2
CB-8	-	-	-
LE-5	40.8	2	2
RET-5	61.2	3	1
TF-5	56.1	3	1
WE-4	40.8	2	2
LE-4	45.9	3	1
RET-4	45.9	3	1
TF-4	45.9	3	1
LE-3	25.5	2	2
RET-3	51.0	3	1
TF-3	35.7	2	2
CB-5	25.5	2	2

*(O,HC,SC) = Oysters, Hard Shell Clams and Soft Shell Clams
*(SCA) = Scallops

NOTE: The maximum flood velocity values of 128 stations in the Chesapeake Bay and its tributaries, used to obtain the above average values, were obtained from the 1993 NOAA Tidal Current Tables.

Table 7. Salinity Growth Range for Four Organisms

CULTURED ORGANISM	SALINITY RANGE (GROWTH)
Oyster	=> 10ppt
Hard Shell Clam	=> 15ppt
Soft Shell Clam	=> 5 ppt
Bay Scallop	=> 20ppt

Table 8. Segments which have a high probability of supporting SAV down to the 1 meter and 2 meter contour (Based on 1989 Chesapeake Bay Monitoring Program water quality data)

Segment No.	Water Quality Suitable for SAV growth down to the 1 meter contour	Water Quality Suitable for SAV growth down to the 2 meter contour
CB-7	*	*
CB-6	*	
CB-8		
LE-5		
RET-5		
TF-5		
WE-4	*	
LE-4		
RET-4		
TF-4		
LE-3	*	
RET-3		
TF-3		
CB-5	*	

One meter suitability was based on the number of SAV one meter habitat requirements met (See Table 1 for these requirements and actual target values). If four or more habitat requirements were met in a segment, the segment was labeled likely to support SAV down to the one meter contour.

Two meter suitability was based on a segment's average light attenuation value. If the value was equal or less than the two meter restoration value of .8 m-, the segment was labeled likely to suppport SAV down to the two meter contour.

Table 9. Likelihood that SAV would grow down to the 2 meter restoration goal based on present, historical and expected distribution and surrounding water quality.

Likelihood that SAV would grow down to the 2 meter contour line.	Distribution	Water Quality 1 meter	Water Quality 2 meter
HIGHEST	Present	*	*
HIGH	Present	*	
MODERATE/HIGH	Historical	*	
MODERATE/LOW	Historical		
LOW	Future/TierIII	*	
LOWEST	Future/TierIII		

Table 10. Range of Values

PARAMETERS	RANGE OF VALUES
Chlorophyll-a	1.1 - 103.5ug/L
Light Attenuation	0.76 - 7.25m-
Dissolved Inorganic Nitrogen	0.023 - 2.648mg/L
Dissolved Inorganic Phosphorus	0.001 - 0.08mg/L
Maximum Current	5.1 - 76.5cm/s
Total Suspended Solids	3.5 - 47.0mg/L

TABLE 11. Pounds of oyster meat harvested in Virginia for the years 1990, 1959, and 1880, and the equivalent amount of hectares necessary to produce these amounts.

Year	Meat Harvested (In millions of pounds)	Number of Ha necessary to produce the amount of meat harvested	
		Ha	5-Ha plots
1990	3.7	65	13
1959	32	552	110
1880	46	799	160

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